INVESTIGATION ON ENGINEERING PROPERTIES OF SOIL IN AKAKI-KALITY SUB CITY, ADDISS ABABA

By

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APPROVAL PAGE

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Acronyms

SBH	Secondary Bore Hole
STP	Secondary Test Pit
PTP	Primary Test Pit
LL	Liquid Limit
PI	Plasticity Index
FS	Free Swell
USCS	Unified Soil Classification System
G_s	Specific Gravity
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
UCS	Unconfined Compressive Strength
AASHTO	American Association of State Highway and Transportation Officials
C	Cohesion force
Φ	Angle of Internal Friction
e_o	Initial Void Ratio
C_c	Compressibility Index
K	Permeability Coefficient

Abstract

Geotechnical soil characterization and mapping is a key for effective engineering practice. This study is then designed to characterize the engineering properties of soil and map the soil distribution in Akaki Kality sub city, Addis Ababa, Central Ethiopia.

Large quantities of drilling and laboratory testing data, both from preexisting and ongoing projects, have been collected, filtered out and finally a geotechnical database has been developed in GIS environment. The output further checked using exploration test pits and subsequent soil sampling and laboratory analysis for the most common soil types in the study area. Further, comparative soil characterizations were conducted with basic soil forming parameters; namely parent rock geology, drainage pattern and topographic features.

From the present study, it was found that the predominant soil types in the study area are classified as high plastic silt (MH), Sandy silt (SM) and high plastic clay (CH) in Unified Soil Classification System (USCS). SC (Sandy clay), ML (low plastic silt) GM (Gravely silt) SM-SC (Sandy silt/ Sandy clay) are rarely exhibited soil types. The soils show a wide range of expansiveness, from non-expansive to highly expansive; medium to very stiff consistency. It is also noticed that when liquid limit (LL) and plasticity index (PI) increases, compression index (Cc) increases. The depth profile generally revealed that black cotton (silty clay/clayey silt) as a top layer, silty clay/clayey silt soil layer, sandy silt/Silty sand layer and sandy gravel layers with variable thickness.

Finally, based on the general findings of the present study, the sub-city geotechnical soil map was developed and also appropriate recommendations have been forwarded.

CHAPTER ONE

Introduction

1.1. Background and Justification

Soil investigation is important and prerequisite for feasible and safe design of structures especially substructure elements and for selection of appropriate earthwork and/or pavement sub grade materials in road and highway constructions. Public building officials may require soil data together with the recommendations of the geotechnical consultant prior to issuing a building permit. In contrast insufficient geotechnical investigations, faulty interpretation of results, or failure to portray results in a clearly understandable manner may contribute to inappropriate designs; delays in construction schedules, costly construction modifications, and use of substandard borrow material, environmental damage to the site, post construction remedial work and even failure of a structure and subsequent litigation.

In a city like Addiss Ababa which is developing at high growth rate and which needs many construction works in the future, geotechnical investigation on the engineering property of soil is very essential. A number of researches related to soil investigation and foundation analysis were done and there are ongoing researches as well in Addis Ababa. To mention undertaken or ongoing researches in Addiss Ababa 'Investigation into some of the engineering properties of red clay soils in Addis Ababa' (Samuel,1989),'Bearing capacity assessment for building foundation using different approaches-A comparative study at Addiss Ababa' (Lamesgen, 2006), 'Settlement analysis on expansive soil in Bole sub city Addiss Ababa' (Eyerusalem, 2006).

Akaki Kality sub city is one of the ten sub-cities of Addiss Ababa, industrial park and companies, condominium, water supply and public residential projects, government and nongovernmental organizations and institutions has been constructed and under construction as well hence, it becomes one of main expansion corridors of the city. Soil identification, characterization and classification has not been studied well or it is too difficult to get compiled research database regarding to soil nature, distribution and engineering properties in the sub city so far.

1.2. Statement of the problem

Defining soil geotechnical properties and mapping their distribution in a certain area is an important database for any effective engineering practice. Geotechnical soil are also relevant for strategic planning of construction, providing efficient site investigation schedule and an input data for upcoming investigations and adopts reference guideline in order to issue construction work permit for public government officials. However, in such maps are not ready compiled in the study area and in Addis Ababa, in general.

Lack of such data forced to do soil investigations repeatedly for each individual projects causing waste of time and resources. Besides, the sub-city authority has no any reference to accredit the soil investigations work for foundations design of civil works in light of having ample data to characterize the soil in the sub-city.

Thus, keeping this in mind the present study was initiated to undertake a comparative assessment of the engineering properties of soils and develop a medium scales geotechnical soil map in Akaki-Kality sub city.

1.3. Objectives of the study

1.3.1. General objective

The general objectives of this thesis project comprehend to define the engineering properties, distribution and characterization of soil in Akaki-Kality sub city.

1.3.2. Specific objective

The general objective is acquired by performing the following specific cases: -

I. To conduct laboratory tests for index and engineering property determination.
II. To classify the soil based on their field description and index properties.
III. To determine free swell and expansive potential of expansive soil in the sub city.
IV. To generate geotechnical soil map.

1.4. Scope and Limitation of the study

The scope of this study is bounded to generate geotechnical soil maps, investigate engineering and index properties and provide pertinent information for further researches /investigations.

The secondary data were obtained from private and governmental laboratories dedicated to geotechnical engineering practice. This imposes an error due to changes in personnel and testing procedures over time. Though data collected from various sources, it was difficult to access data for future expansion locations currently serve as cultivation area.

1.5. Structure of the thesis

This thesis work is structured in six chapters. The first chapter deals with an introduction part in which problem background, objective of the study, scope and limitation of the research are addressed.

Second chapter presents the brief literature review part of the thesis. In the chapter soil formation and deposit regarding to parent material, topography and drainage and climate factors are reviewed. General soil types depending on soil particle size and shape and also mineralogical composition, parameters of soil properties (physical, index and engineering) are addressed too.

The third chapter deals with the description of the study area. This chapter tries to discuss the geology, soil characteristics, topography, drainage conditions and climatic conditions of the study area.

The fourth chapter tries to present the methodology of the research work. In this chapter secondary, primary data sources of engineering and index properties of the soil are explained.

In the fifth chapter result discussions of test results is presented. In Chapter six conclusions from test results are drawn and finally recommendation is presented.

CHAPTER TWO

Literature Review

2.1. General

Soil is defined as a natural aggregate of mineral grains, with or without organic constituents that can be separated by gentle mechanical means such as agitation in water. By contrast rock is considered to be a natural aggregate of mineral grains connected by strong and permanent cohesive force. The process of weathering of rock decreases the cohesive force binding the mineral grains and leads to the disintegration of bigger masses to smaller and smaller particles. Soils are formed by the process of weathering of the parent rock (Terzaghi, K, Ralph 1996).

The varieties of soil materials encountered in engineering problems is almost limitless ranging from hard, dense, large pieces of rock through to gravel, sand, silt, and clay to organic deposit of soft compressible organic peat. At any given site, a number of different soil types can be present, and the composition may vary over intervals of a little as a few inches. (Beza, 2008)

The properties and characteristics of soils vary from place to place laterally or vertically. The tests required for determination of engineering properties are generally elaborate and time consuming. Sometimes the geotechnical engineer is interested to have some rough assessment of the engineering properties without conducting elaborate tests. This is possible if index properties are determined. The properties of soils which are not of primary interest to the geotechnical engineer but which are indicative of the engineering properties are called index properties (Adem, 2006)

2.2. Soil formation and soil deposits

Soils are formed by the process of weathering of the parent rock. The weathering of the rocks might be by mechanical disintegration, and/or chemical and biological decomposition. The properties of the soil materials depend upon the properties of the rocks from which they are derived.

The main factors imposing soil formations are, parent materials i.e. geology of the area, topography, drainage and climate.

2.2.1. Parent materials

There are two main variables in parent materials that affect soils: grain size and composition. Grain size is the main determinant of soil texture. Texture influences the soil structure, consistency, cat ion exchange capacity, profile drainage, moisture retaining capacity and organic content (Girma, 1962). Soil composition is composed of mineral matter and organic matter and contains pore spaces filled with water or air and soluble nutrients. Organic matter serves as a binder for mineral particles, contributing to soil structure so soil composition is one of the aids to the formation of soil.

2.2.2. Topography

Topography has a major influence on drainage characteristics which in turn is known to have a major effect on soil mineralogy. According to (Dagnachew, 2011) topography controls the rate of weathering by partly determining the amount of available water and the rate at which it moves down through the zone of weathering.

Topography has a strong and fairly consistent influence on the weathering process, and thus on the type of clay minerals formed, especially in the wet tropics. In hilly and mountainous areas, the soil is well drained and seepage flow has a strong downward component. This leads to the formation of low-activity clay minerals, especially kaolinite. In wide, flat areas, drainage of any sort is much more limited, and moisture movement occurs primarily as a result of seasonal changes. (Robert D.H, 1981).

The steepness of the slope affects the amount of deposition or erosion of soil material. Soil developed on flat terrain is the most developed as there is no loss or gain of material to slow the soil formation process. The aspects of the slope affect the amount of water that moves through the soil. (Jhon.A et al, 2002).

2.2.3. Drainage

Flowing water/stream is one of the most important agents of transportation of soils. Swift running water carries a large quantity of soil either in suspensions or by rolling along the bed. Water erodes the hills and deposits the soils in the valleys.

The size of soil particles carried by water depends upon the velocity. The swift water can carry the particles of large size such as boulders and gravels. With a decrease in velocity, the coarse particles get deposited. The finer particles are carried further downstream and are deposited when the velocity reduces. A delta is formed when the velocity slows down to almost zero at the confluence with a receiving body of still water such as a like, a sea or an ocean. (Arrora, 2004)

2.2.4. Climate

Climate is the principal factor governing the rate and type of soil formation. The two important components of climate are the amount and distribution of precipitation, and temperature. Reaction increases by a factor of 2 or 3 for every 10 °c rise of temperature (Budhu, 2000).

The amount and distribution of precipitation affects the availability of moisture and the relative humidity of the soil atmosphere; it influences the concentration or chemical activities of solutions in the system.

2.3. General types of Soils

On the basis of origin of their constituents soils can be categorized in to:-

- **i)** Residual soil
- **ii)** Transported soil

Residual soils are those that remain at the place of their formation as a result of the weathering of parent rocks. The depth of residual soils depends primarily on climatic condition and the time of exposure. In some areas, this depth might be considerable. In temperate zones residual soils are commonly stiff and stable. An important characteristic of residual soil is that the sizes of grains are indefinite. For example, when a residual sample is sieved, the amount passing any given sieve size depends greatly on the time and energy expended in shaking, because of the partially disintegrated condition.

Transported soils are soils that are found at locations far removed from their place of formation. The transporting agencies of such soils are glaciers, wind and water. The soils are named according to the mode of transportation. Alluvial soils are those that have been transported by running water. The soils that have been deposited in quiet lakes are lacustrine soils. Marine soils are those deposited in sea water. The soils transported and deposited by wind are aeoliansoils. Those deposited primarily through the action of gravitational force, as in landslides, are colluvial soils. Glacial soils are those deposited by glaciers. Many of these transported soils are loose and soft to a depth of several hundred feet. Therefore, difficulties with foundations and other types of construction are generally associated with transported soils. (Murty, 2004)

2.4. Laboratory tests

The primary purpose of laboratory testing is to measure physical soil properties utilizing standard repeatable procedures to analyze soil behavior under proposed ground loading conditions. Laboratory test data are also used to check field soil classifications from the subsurface field exploration program. Details regarding specific types of laboratory tests and their use are provided in Sabatini, et al (FHWA, 2002).

Laboratory soil testing is used to estimate strength, stress\strain, compressibility, and permeability characteristics. See Sabatini, et al. (FHWA, 2002) and Section 10, AASHTO LRFD (2014) for specific guidance and requirements regarding laboratory testing.

Soil strength tests shall be performed on high quality, relatively undisturbed in-situ specimens. However, it is difficult and frequently impossible to sample, transport, extrude and set-up testing for granular, cohesion less soils (Sand or Gravel) without excessively disturbing or completely obliterating the soil specimen.

Improper storage, transportation, and handling of in-situ soil samples can significantly alter their laboratory tested geotechnical engineering properties. Quality control (QA) requirements are provided in Mayne, et al. (FHWA, 1997).

2.4.1. Index Properties

In nature, soils occur in a large variety. However, soils exhibiting similar behavior can be grouped together to form a particular group. Engineers are continually searching for simplified tests that will increase their knowledge of soils beyond that which can be gained from visual examination without having to resort to the expense, detail, and precision required with engineering properties tests. These simplified tests provide indirect information about the engineering properties of soils and are, therefore, called index tests.

2.4.1.1. Atterberg limits

Atterberg defines the boundaries of several states of consistency for plastic soils. The boundaries are defined by the amount of water a soil needs to be at one of those boundaries. The boundaries are called the plastic limit and the liquid limit, and the difference between them is called the plasticity index. The shrinkage limit is also a part of the Atterberg limits (Arora et al, 2007).

The results of this test can be used to help predict other engineering properties. Water content greatly affects the engineering behavior of fine-grained soils. In the order of increasing moisture content, a dry soil will exist into four distinct states: from solid state, to semisolid state, to plastic state, and to liquid state. Between the solid and semisolid states is shrinkage limit, between semisolid and plastic states is plastic limit, and between plastic and liquid states are liquid (Arora et al, 2007).

2.4.1.2. Specific gravity

The term specific gravity of soil actually refers to the specific gravity of the solid matter of the soil, which is designated Gs. The specific gravity of solids is normally only applied to that fraction of the density of the minerals making up the individual soil particles. However, as a general guide, some typical values for specific soil types are as follows (Das, 2007).

The specific gravity of the solid substance of most inorganic soils varies between 2.60 and 2.90. Sand particles composed of quartz have a specific gravity ranging from 2.64 to 2.66. Inorganic clays generally range from 2.70 to 2.90. Soils with large amounts of organic matter or porous particles (such as diatomaceous earth) have specific gravities below 2.60. Some range as low as 2.00.

2.4.1.3. Particle-size distribution

In any soil mass, the sizes of the grains vary greatly. To classify a soil property grain size distribution is required. The grain size distribution of coarse grained soil is generally determined by means of sieve analysis. For a fine grained soil, the grain size distribution can be obtained by means of hydrometer analysis (Murthy, 2003).

In general, a soil sample may contain both coarse grained particles as well as fine particles and hence both sieve and hydrometer analysis may be necessary. The sieve analysis is, however, the true representative of grain size distribution, since the test is not affected by temperature. (Punmia et al, 2006).

2.4.1.4. Free Swell

The free swell test is one of the most commonly used simple tests in the field of geotechnical engineering for getting an estimate of soil swelling potential and to identify whether it is expansive or not. Free swell also termed as free swell index. It is the increase in volume of soil without any external constraint when subjected to submergence in water.

Range	Free swell %
Expansive	>100
Marginal	50-100
Non expansive	<50

Table 2.1. Expansive characteristics of soil

2.4.2. Engineering Properties

The basic engineering properties of soil are:-

i) Strength
ii) Compressibility
iii) Permeability characteristics of a soil.

2.4.2.1. Strength properties

Soil strength is the resistance to mass deformation developed from a combination of particle rolling, sliding, and crushing and is reduced by any pore pressure that exists or develops during particle movement. This resistance to deformation is the shear strength of the soil as opposed to the compressive or tensile strength of other engineering materials. The shear strength of soil is one of the most important aspects of geo technical engineering (Day, 2006).

The bearing capacity of shallow and deep foundations, slope stability, retaining wall design and pavement design are all influenced by the shear strength of the soil (Jones and Holtz, 1973). Direct shear test and unconfined compressive strength (UCS) tests are the most common soil shear strength tests.

Direct shear test: - are usually carried out to measure and determine the shear strength of soils, by sliding one portion of a soil relative to another. The shear strength is measured in terms of two soil parameters: inter-particle attraction or cohesion C, and resistance to inter-particle slip called the angle of internal friction Ø (Gilloth, 1962). According to Terzaghi and Peck (1967) the cohesion, C, is the component of shearing resistance due to internal forces holding the particles together in a solid mass; while tan is the component of shearing resistance due to interlocking of soil particles and friction between them when subjected to normal stress.

Unconfined Compression Strength (UCS)

The Unconfined Compression Test (UCS) is a special case of the Unconsolidated Undrained triaxial compression Test. In this case, no confining pressure is applied to the specimen. The UCS test is one of the easiest and simplest tests for a quick estimate of the shear strength of cohesive soils.

The test provides an immediate approximate value of the compressive strength of the soil, either in the undisturbed or the remolded condition. It is also widely used to determine the consistency of saturated clays and other cohesive soils.

The maximum load per unit area is defined as the unconfined compressive strength, qu For soils, the undrained shear strength (Su) is necessary for the determination of the bearing capacity of foundations, dams, etc. The undrained shear strength (Su) of clays is commonly determined from an Unconfined Compression Test. The undrained shear strength (Su) of a cohesive soil is equal to one-half the Unconfined Compressive Strength (qu) when the soil is under the Ø= 0condition (= the angle of internal friction). The most critical condition for the soil usually occurs immediately after construction, which represents undrained conditions, when the undrained shear strength is basically equal to the cohesion(C).

Consistency	**qu (KN/M2)**
Very Soft	0-24
Soft	24-48
Medium	48-96
Stiff	96-192
Very Stiff	192-383
Hard	>383

Table 2.2. Consistency and unconfined compression strength of clay soils (Braja, 2008)

2.4.2.2. Compressibility

When a soil mass is subjected to a compressive force, its volume decreases. The property of a soil due to which a decrease in volume occurs under compressive force is known as the compressibility of soil. The compression of soil can occur due to:-

- ✓ Compression of solid particles and water in the voids
- ✓ Compression and expulsion of air in the voids
- ✓ Expulsion of water in the voids

Consolidation and compaction are two basic compressibility characteristics of soils.

Consolidation

It is entirely due to expulsion of water from the voids. It is similar to the action of squeezing of water from a saturated sponge under pressure. The soil behaves as a saturated sponge. As the consolidation of soils occurs, the water escapes. The solid particles shifts from one position to the other by rolling and sliding and thus attain a closer packing.

Settlement of a structure is its vertical, downward movement due to a volume decrease of the soil on which it is built. In other words, the settlement is the gradual sinking of a structure due to compression of the soil below. A study of consolidation characteristics is extremely useful for forecasting the magnitude and time of the settlement of the structure.

A consolidation test, also called an odometer test is a measurement of how soils compress when saturated with water and exposed to varying amounts of load, or varying weights of the soil. Saturated conditions exist when water is added until no more can be absorbed by the soil.

Among the compressibility properties, compression index is by far the most important engineering property to estimate settlement of foundations. It is defined as the slope of void ratio versus logarithm of the applied load curve in one dimensional consolidation test graph (Budhu, 2011).

Laboratory tests conducted on consolidation characteristics of expansive soil in Addiss Ababa shown that the value of consolidation parameters of the soil are smaller than the values for clay soil in other parts of the world. This means that the soil has relatively lesser compressibility and the rate of consolidation is also smaller as well. (Mesfin, 2005)

Compaction

Compaction means pressing the soil particles close to each other by mechanical methods. Air during compaction is expelled from the void space in the soil mass and, therefore the mass density is increased. Compaction of soil mass is done to improve its engineering properties.

Compaction generally increases the shear strength of soil, and hence the stability and bearing capacity. It is also useful in reducing the compressibility and permeability of the soil.

Compaction is an entirely different process than consolidation, even though both the process causes a reduction in the volume. Compaction is rapid process of reduction of volume by mechanical which expelled out air from the voids at the unaltered water content by means such as rolling, tamping and vibration, whereas consolidation is a gradual process of reduction of volume by squeezing out of water from the soil under sustained static loading. (Arora, 2003)

2.4.2.3. Permeability

The expulsion of water from the voids of a saturated clay soil by an externally applied load in the consolidation process and the change in volume associated with such a process are essentially hydraulic problem. Specifically, it is a problem of permeability of soil to water. Therefore, the rate of consolidation depends on the permeability of the soil. The permeability of the soil by itself is a function of the soil type, size and shape of the soil particles (round, angular, or flacky), and thus, up on the size and geometry of voids. Also, the resistance is a function of the temperature of water (viscosity and surface tension effect). (Jumikis, A.R, 1984)

Permeability is a very important engineering property of soils. Knowledge of permeability is very essential in a number of soil engineering problems, such as settlement of buildings, yield of wells, seepage through and below the earth structures. (Murty,2004).

2.5. Soil Classification

Soil classification is a systematic method of categorizing soils into various groups and subgroups according to their probable engineering behavior without detailed descriptions.

It has been stated earlier that soil can be described as gravel, sand, silt and clay according to grain size. Most of the natural soils consist of a mixture of organic material in the partly or fully decomposed state. The proportions of the constituents in a mixture vary considerably and there is no generally recognized definition concerning the percentage of, for instance, clay particles that a soil must have to be classified as clay, etc. The systems that are quite popular amongst engineers are the AASHTO Soil Classification System and the Unified Soil Classification System (USCS). When a soil consists of the various constituents in different proportions, the mixture is then given the name of the constituents that appear to have significant influence on its behavior, and then other constituents are indicated by adjectives. Thus sandy clay has most of the properties of clay but contains a significant amount of sand.

2.6. Geotechnical soil map

A map is a symbolic depiction emphasizing relationships between elements of some space such as objects, regions or themes. Many maps are static, fixed to paper or some other durable medium, while others are dynamic or interactive. The space being mapped may be two dimensional, such as the surface of the earth, three dimensional, such as the interior of the earth, or even more abstract spaces of any dimension based on the function of the map.

Geological maps show not only the physical surface, but characteristics of the underlying rock, fault lines, and subsurface structures. last but not the least geotechnical soil maps are important to reduce the time required in making surveys for engineering locations, and the association of engineering performance with the soil type name provide a convenient means of cataloging and filing of soil information.

Soil mapping is the process of delineating natural bodies of soils, classifying and grouping the delineated soils into map units, and capturing soil property information for interpreting and depicting soil spatial distribution on a map.Geotechnical soil maps are important to make reconnaissance surveys, to locate quarry locations, to organize and check field surveys and to correlate pavement and structure performances with soil types.

In soil-reconnaissance surveys, the maps can be used for preliminary site selection by taking advantage of favorable soil and drainage conditions. Soil mapping making it possible to note the areas where these conditions prevail before ever going into the field. Fine and course soil constitute deposits can be located readily. Soil maps can be used to a great advantage in organizing and checking field sampling. The intelligent use of engineering soil surveys and maps can reduce the time required in making surveys for engineering locations and provide a convenient means of cataloging and filling of soil information.

2.7. Review of previous researches

Geotechnical soil map is very important in providing necessary data or information that can be used in designing civil engineering structures. Many researches accomplished related with soil characterization and geotechnical soil mapping.

Morin and Perry (1971) studied the origin and mineralogical composition of Ethiopian red clay soils. According to their study Ethiopian red clay soils are principally residual, derived from the weathering of volcanic rocks. The parent rock for black and red clays in Ethiopia is mainly olivine basalt, basalt and trachyte. Ethiopian red clay soils have developed where rain fall is plentiful and drainage is good, and contain Kaolinite and Halloysite as the principal clay minerals, but Montmorillonite is also frequently present in significant amounts. The red color of the Ethiopian soils indicates the presence of iron.

Dangachew Debebe (2002) has studied about investigation on engineering properties of soil in Adama town. The result of Atterberg Limit of the soil samples the soil under investigation is inorganic and the grain size analyses indicate that the dominant proportion of soil particle in the research area is silt. The coefficient of permeability of soil under investigation shows that the soil under investigation is practically impermeable to very low permeability. Over-consolidation ratios of the soils are more than one, so the soil in the study area is over consolidated in its natural state.

Samuel (1989) has studied about investigation in to some of engineering properties of Addis Ababa red clay soils. Based on experimental results from 13 samples around Kolfe, Rufael and Semen Gebeya areas he found out the depth of red clay soil in Addis Ababa ranges from few centimeters to about 10 meters. The thickness of the soil is found to be one and half meter in Semen Gebeya and Rufael areas and more than 3m in Kolfe area and finally index property test result indicates the soil is not potentially expansive.

Belton and Stewart, 2002; Dai et al., 2001; Sun, 2010; Kolat, 2012; Sener et al., 2006; Sugen and Doyuran, 2004 have indicated the need for a systematic study and evaluation of parameters that are important for different multivariate decision making tasks using GIS-based analysis.

Tonkin & Taylor. 2008; Cavaleiro et al., 2006; Roch, 2000; Khizar, 2003; Carrara et al., 1999; Jankowski, 1995 have also mentioned that in the preparation of geotechnical maps and plans related to engineering problems, and for proper handling of large volumes of information related to geotechnical data, the use of software such as the Geographical Information Systems (GIS) has become an inevitable tool.

Khizar (2003) has stressed the need of geotechnical evaluation to determine the suitability of the foundation of residential areas and to ensure the stability/safety of any building in an area. Furthermore, it is also stated that the areas where the settlements are high and dense prior to geotechnical evaluation, preparation of geotechnical map helps to check the suitability of the area for such density and also to determine the precautions that are needed for safer planning actions or modifications.

(Luis M.Diaz-Diaz et al, 2017) establishes an unprecedented geotechnical map of Avilés city and surroundings (NW Spain) at scale1:25,000. The mapping procedure is mainly based on exhaustive fieldwork and many unpublished geotechnical data. All the available data were integrated in a geodatabase implemented through a GIS. It comprised two main data sets: (1) geographic base and (2) geologic and geotechnical data. This geo database was fundamental in the procedure of preparation of urban mapping.

CHAPTER THREE

Description of the study area

3.1. Location of the study area

Addis Ababa is the capital city of Ethiopia, founded in 1886 by Emperor Menilk II, as initially a king of the Shewa province. It is the largest city in Ethiopia with a plot area of 527 square kilometers, with a population of 3,384,569 according to 2007 population census with annual growth rate of 3.8%. Addis Ababa lies at an altitude of 2,300 meters (7,500 Feet) a.s.l. and located at $9^{0}5'40''$ latitude and $38^{0}76'36''$ longitude. The city is divided into ten boroughs named sub cities and 99 weredas.

Akaki kality sub city is one of the sub cities of Addiss Ababa which encounter largest plot area 118.08 square kilometer, with a population of 195,273 and located at $8^{0}55'38''$ latitude and $38^{0}46'5''$ longitude.

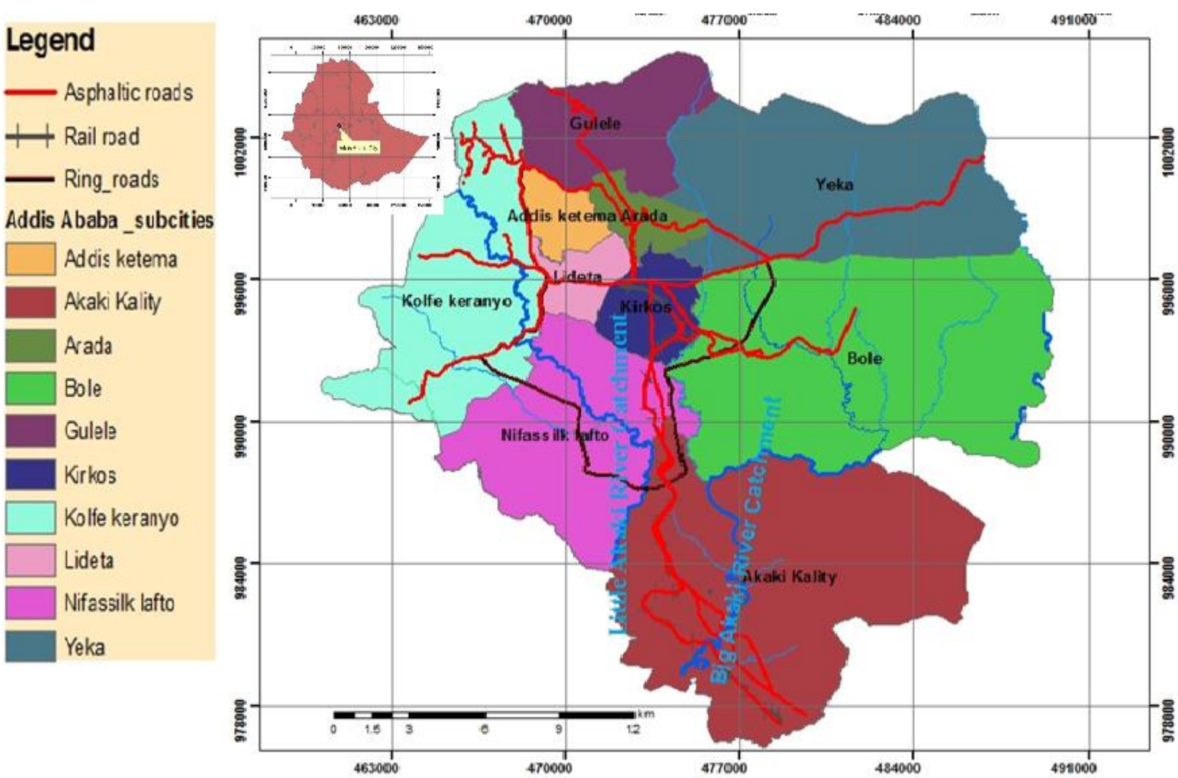

Fig 3.1. Location map of the study Area

3.2. Geology of the study area

The geological history of the studied area is an integral part of the evolution and development of the Ethiopian Plateau and the Rift system, because of its location at the western margin of the Main Ethiopian Rift (MER). The area is covered by different volcanic rocks with both acidic and basic compositions and overlain by fluvial and residual soils varying in thickness from a few cm to several meters below natural ground level. Black cotton soil is the predominant soil type. The geology of Akaki-Kality Sub city compiled by (Haileselassie , et.al.,1989, as cited in Habtamu, 2010), (Assegid,2007), (Efrem ,2009) and (WWDSE ,2008) comprises of mainly Akaki (Bofa) basalt. The geological map of the study area is given in Fig.3.2.

The lithological composition of the study area is divided in to three types:-

i) Akaki Basalt (Bofa Basalt): - Scoria and scattered cones with associated volcanic lava which constituents around 80% of the plot area of AkakiKality.

Bofa Basalts outcrop southward from Akaki River where they appear in the form of boulders reaching a thickness of 10 m. They are restricted and dominated in the southern and southeastern part of the sub city. This rock is underlain by the tuffs which cover the welded tuff (Hailesellasie, et.al., and Getaneh, 1989 as cited in Zeleke, 2013). It is coarse grained porphyritic olivine basalt. It is highly vesicular basalt and at places the vesicles were filled by carbonate minerals. It is consisting of scoria and spatter cones with associated lava flows (WWDSE, 2008).

ii) Central volcanic of Wochecha, Furi, yerer porphyritic trachytic lava: - at the northern portion of the study area.This unit mainly covers relatively elevated areas of the study area. Volcanic mountains such as Furi in southern part and Yerer in Northeastern part of the study area are mainly trachyte in composition (Kebede et al., 1990). According to EfremBeshawered (2009), this unit is composed of trachyte and pyroclastic material. It is light to dark grey, aphanitic to medium grained in texture with vesicular varieties mostly at its lower part. At some places it shows layering and its base is dominated by trachy basalt to basalt rock type (Assegid, 2007).

iii) Addis Ababa basalt: - Alkaline and olivine basalt lava flows. This unit, which is mainly present in the central part of the town, is underlain by the Entotosilicics and overlain by Lower welded Tuff of the Nazaret group. The distribution of plagioclase porphyritic basalt is almost the same as that of the olivine prophyritic basalt. (Hailesellase et.al., and Getaneh, 1989 as cited in Habtamu Solomon, 2010).

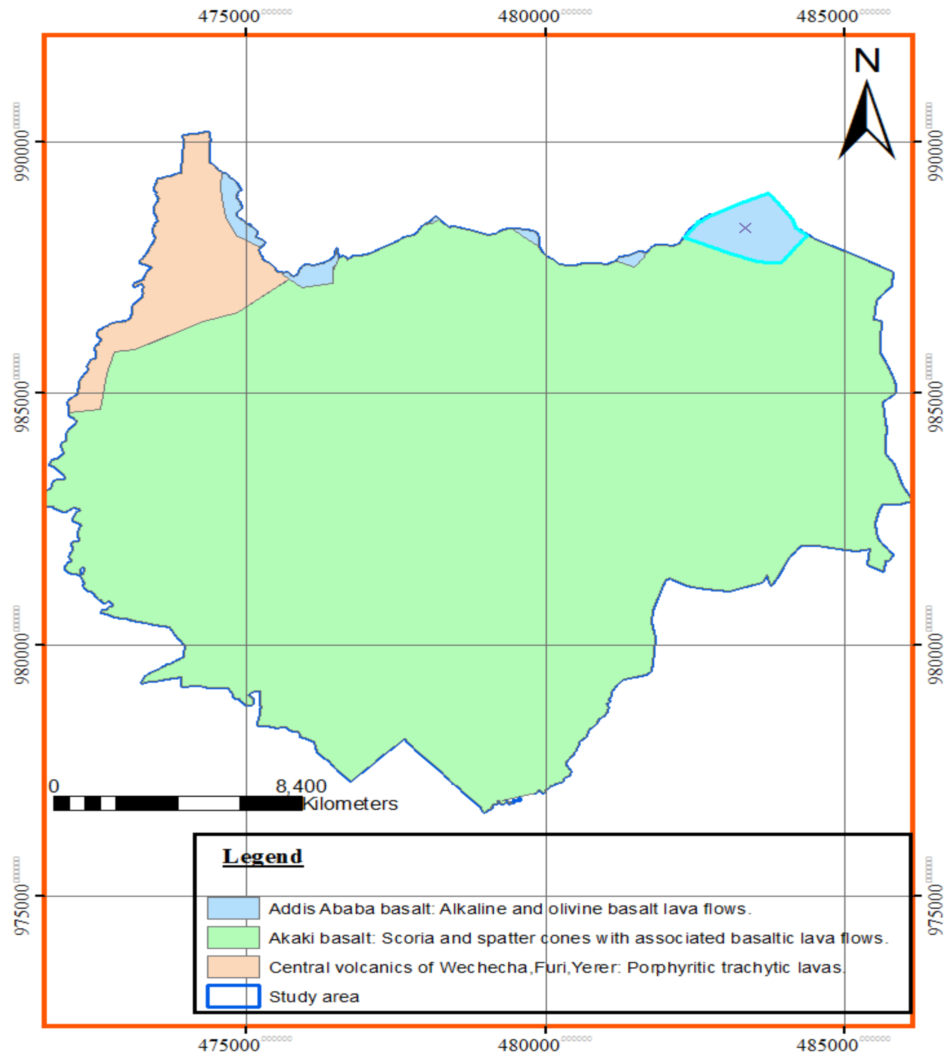

Fig.3.2. Geological map of Akaki Kality

3.3. Topography

Topographic relief has an important role in soil formation. For a deep residual soil to develop, the rate at which weathering advances into the earth's crust must exceed the rate of removal of the products of weathering by erosion. Topography controls the rate of weathering by partly determining the amount of available water and the rate at which it moves through the zone of weathering. In addition to this, it also controls the effective age of the profile by controlling the rate of erosion of weathered material from the surface. Thus, deeper residual profiles will generally be found in valleys and gentle slopes rather than on high ground or steep slopes. (Blight,1997 as cited in Hana, 2008).

The study area comprises mostly gently flat topography and its elevation ranges from 2044m to 2354m a.s.l. Gentle sloped sites indicated chlorite, vermiculite, montmorillonite and kaolinite in weathering sequence. Samples taken from a flat site with impeded drainage have shown montmorillonite as the predominant mineral. Flatter slopes and poor drainage favor the formation of montmorillonite. All these points indicate the significance of studying/analyzing the nature of a given soil relative to the specific conditions under which it is formed. Elevated areas within the study area north and north east peripheries possess residual soils few centimeters in depth. Flat low land locations, of southern peripheries and along the main river basin (Akaki River) transported soil deposits are predominant.

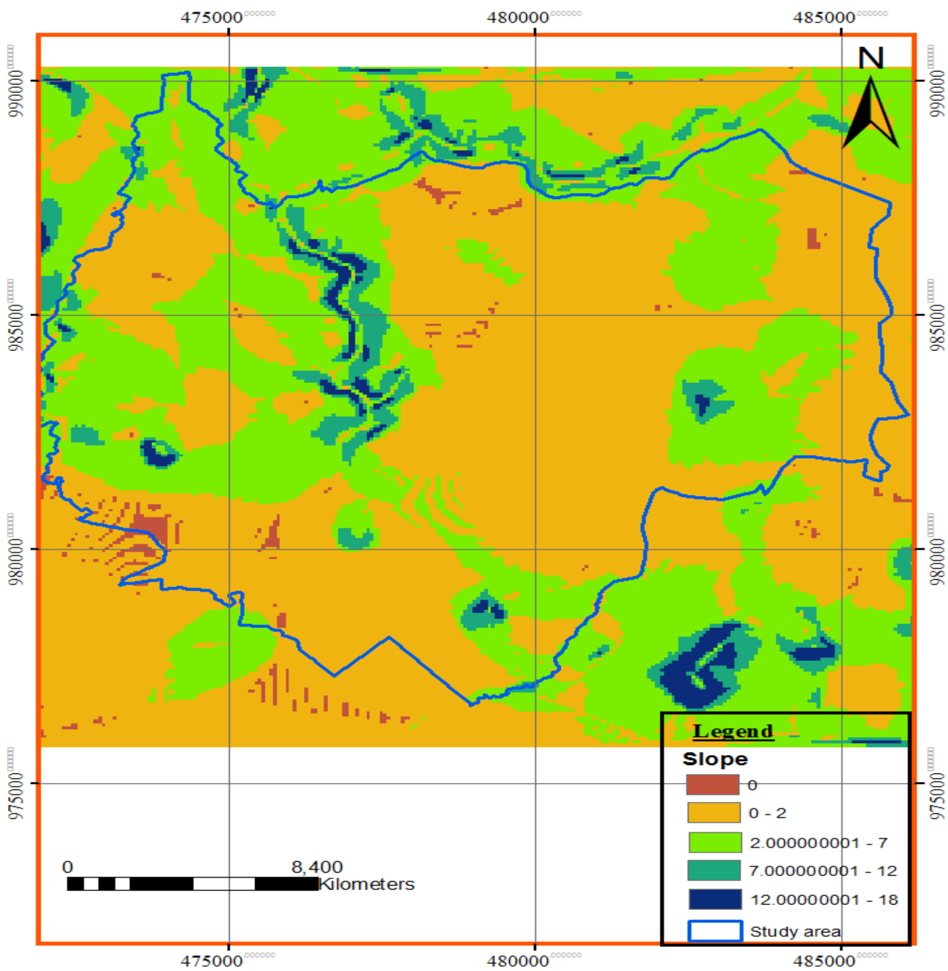

Fig.3.3. Topographic map of Akaki Kality

3.4. Drainage

On top of the hills and ridges streams are dense and form radial drainage pattern, whereas on slopes and on most parts of the study area they form dendritic pattern. The major river that drains within the study area is the Akaki River. Several perennial and intermittent rivers join the major river (Figure 3.4). The drainage pattern is governed by the geology and physiographic set up of the area (Tamiru et al., 2006). Most of the tributaries in the study area are estimated to drain from higher topographic place in north eastern part of the sub city and north top ridges of Addiss Ababa as Entoto ridge, and flows towards flat lying locations.

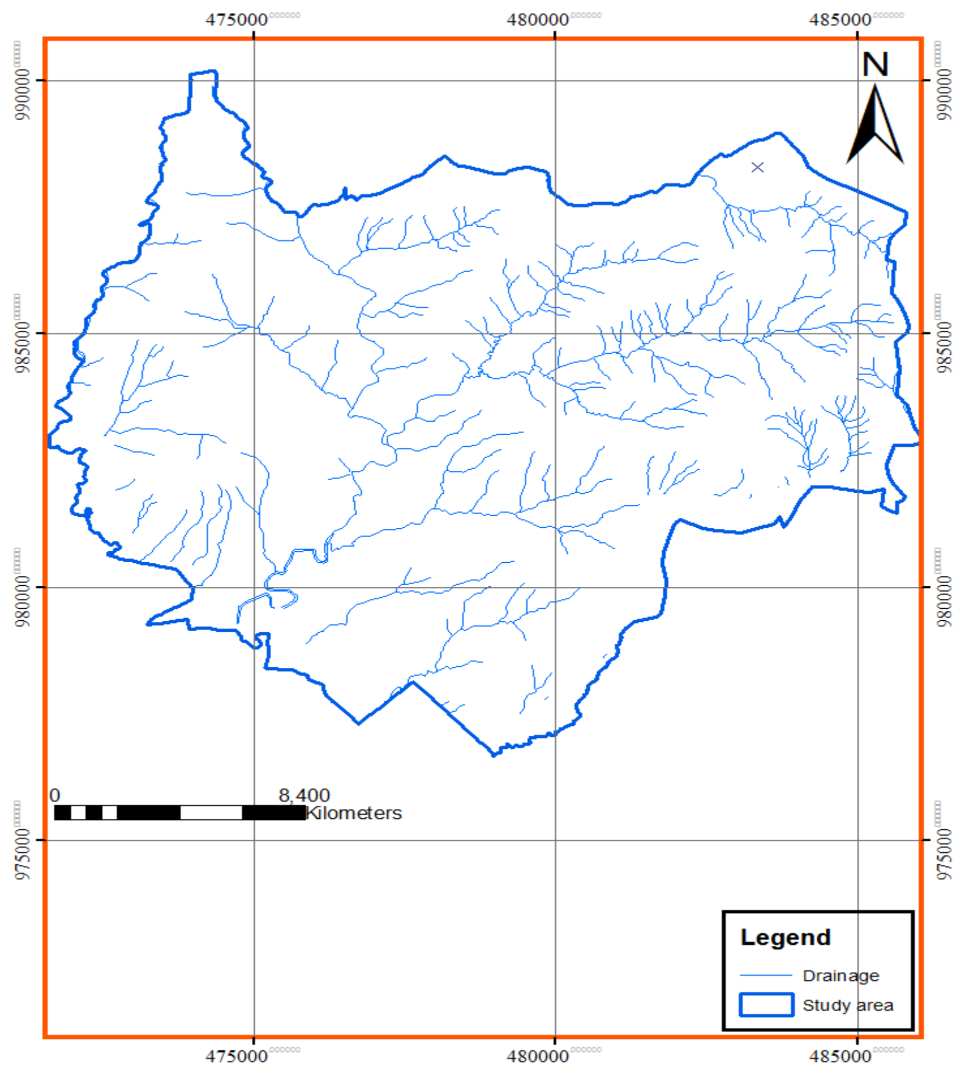

Fig 3.4. Drainage map of Akaki Kality

3.5. Climate

Climate is the principal factor governing the rate and type of soil formation. The two most important components of climate are the amount and distribution of precipitation, and temperature.

The two main rain fall parameters most widely available are the mean annual total and the length of the dry season. The amount and distribution of precipitation affects the availability of moisture and the relative humidity of the soil atmosphere; it influences the concentration or chemical activities of solutions in the system (Gilloth, 1962).

3.5.1. Rainfall

From engineering geological point of view, variations in rainfall brings fluctuations of the groundwater table, thereby producing variations in the moisture content or degree of saturation of the underlying earth materials. The moisture content variation has a greater impact on the engineering properties of earth materials as strength of materials decreases with increase in moisture content.

Station	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Ann.Mean
A.A. Bole (1964-2009)	13.7	37.4	68.6	93	76.4	119	235.4	242.5	143.3	32.7	7.2	5	1074
AkakiBeseka (1951-2009)	14	36.8	67.5	91	67.1	123	264.1	283.9	131.1	24.5	3.8	3.1	1109
AA Obs T/Haimanot (1900-2009)	16.4	42.9	65.9	93.4	85.5	131	259	278.4	175.1	38.1	7.5	9	1201
Mean Monthly	14.7	39	67.3	92.5	76.3	124	252.8	268.3	149.8	31.8	6.2	5.7	1128

(Sources: National Meteorological Services Agency)

Table 3.1. Mean monthly and Mean annual rainfall of Addis Ababa (1900 to 2009)

In Addis Ababa, rainfall intensity variation is attributed to differences in topography. The high elevated areas such as the Entoto receive relatively greater precipitation than lowland areas around Bole and Akaki (Table 3.1). According to National Meteorological Services Agency (NMSA) station located at A.A Bole, A.A Observation T//Haimanot and AkakiBeseka with elevation 2350, 2408 and 2000m a.s.l.

As indicated in Table 3.1 the precipitation occurs throughout the year and shows variation in amount from month to month. The monthly mean records of rainfall at Akaki Beseka station shows that the mean annual rainfall for the years 1951 to 2004 was 1109mm.

3.5.2. Temperature

Under normal conditions, air temperature decrease with increasing altitude at a mean rate of 0.7°C for every 328 feet (Fetter, 1994 as cited in Hana, 2008**).** The average temperatures are typically tropical to sub-tropical and fluctuate by 5^0C between the coldest and warmest months. (Griffiths, 1972 as cited in Habtamu,2010).

The mean monthly maximum and minimum temperature records of National Meteorological Services Agency (NMSA) station in A.A Observation, Akaki, Bole and Entoto station were utilized to calculate monthly and annual average temperature. The computed average maximum and minimum temperature is presented in Table 3.2 below.

Akaka station records the highest amount of average annual temperature in comparison with other three recording stations. This shows that, like the rainfall, there is also variation in the amount of temperature within Addis Ababa with differences in altitude.

Station	Jan.	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Ann. Average
Intoto (1989-2009)	19.9	21.1	20.6	20	19.7	17.8	16.2	16.4	16.7	18.2	19.4	18.8	17.06
AA Obs (1980-2009)	24.3	25	25.7	24.9	25.3	23.6	21.2	21	22	23.1	23.3	23.1	23.54
AA Bole (1980-2009)	23.85	24.7	26	25.1	25.1	23.2	21.1	21	21.7	23.1	23	23	23.4
Akaki (1997-2009)	26.5	27.6	28	27.8	28.2	25.9	24.2	24	25.1	26	25.8	25.9	26.25
Average Monthl	23.63	24.6	25	24.4	24.5	23.7	20.6	20.6	21.4	22.6	22.9	22.7	22.56

Table 3.2. Mean Monthly and Mean Annual temperature of Addis Ababa (1980 to 2009)

3.6. Soil

The soil development in Addis Ababa area is mostly due to the physical disintegration and chemical decomposition of volcanic rocks. The weathering products are either remaining in places and form residual soils or transported and deposited in the low lying flat lands and depressions (Tamiru Alemayehu *et al.,* 2006).

In the localities where the topography is plain to gentle there is thick soil profile. The type of parent material and the length of time to which the parent material is subjected to weathering, control the variation in the thickness of soil. Thus, old basic and acidic rocks that outcrop in the central, western and southwestern parts of Addis Ababa are weathered and form thick soil profile. In places where young basalt and welded tuffs occur, the thickness of the soil cover is reduced (Tamiru Alemayehu et al., 2006).

The deterital materials that are derived from elevated areas of Entoto, Wechecha, Furi and Yerer are transported and deposited in the piedmont and along the stream courses of Addis Ababa. It covers most parts of Mekanisa, Ayere Tena, Kaliti, Akaki, Lideta, and Bole. The soil is black in color and the thickness varies from place to place primarily depending on the slope of the area. More specifically the engineering geological soil unit in Addis Ababa area are grouped into their genetic soil units as alluvial, alluvial fan, colluvial, residual and lacustrine soils (Kebede Tsehayu and Taddesse Hailemariam, 1990)

The differences observed in the type and development of soils in the city depends mostly on the topography, climate, parent rock and the degree of weathering. The detrital materials that are derived from elevated areas of Addis Ababa are transported and deposited in the piedmont and along the stream courses of Addis Ababa. It covers most parts of Akaki-Kality. The soil is black in color and the thickness varies from place to place primarily depending on the slope of the area.

The alluvial soils which include channel and terrace deposits are found along Akaki River. The alluvial soils consist of more or less stratified deposits of gravel and clay transported by streams. (Kebede *et a*l.,1990). From visual inspection, soil types at the north and northeastern parts of the study areas (which are highly elevated areas) are predominantly residual soils. Samples taken at lower elevated areas such as south and south west parts the soil type is predominantly transported soil especially highly expansive clays.

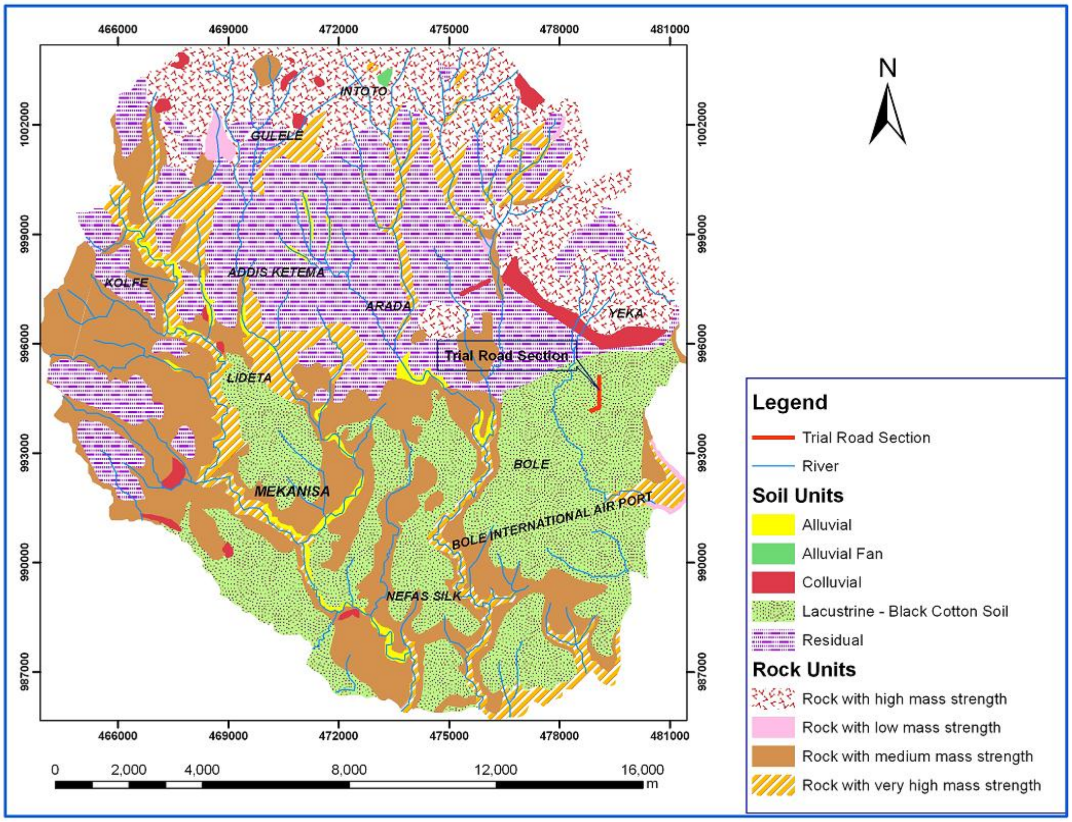

Fig 3.5. Engineering soil map of Addis Ababa (Kebede Tsehayu et al., 1990)

Alluvial fan is deposited where there is a decrease in gradient from a hill to a plain along a river section. It is coarser near the mouth of the river and become finer outwards and found in the Entoto region dissected by deep gullies (Kebede Tsehayu and Taddesse Hailemariam, 1990).

Residual soils developed in situ by the decomposition of rocks are mainly located in Gulele and Kolfe area. In some localities reddish brown soil with a thickness of more than 10m is commonly seen. Lacustrine soils, alternatively named as black cotton soil, are found in Bole, Lideta and Mekanisa areas as these areas are flat and relatively low lying. Observations and tests show. The predominant soil types with in Akaki Kality are, residual soil at north and north east boundaries, black cotton soil at flat, poorly drained portions southern boundaries and alluvial deposit at the downstream portion of Akaki river.

CHAPTER FOUR

Methodology

4.1. General

At an early stage the collection and review of all previous publications and maps about the study area were accomplished. The geotechnical factors in the study area have been assessed through field investigation and existing data evaluation. The assessment was mainly geared towards identification and characterization of major factors that influence the generation of geotechnical mapping. The input data sources used to generate the geotechnical and related factors are topographic maps, geological map and primary data from test pits and secondary bore hole and test pit investigation test results.

Site reconnaissance or visual inspection is a preliminary stage of data collection which provides necessary information about the study area. Engineering soil characterization deals with soil identification, classification and distribution. Soil can be identified from preliminary visual site inspection or laboratory test results. The distribution of soil substantially depends on basic soil formation parameters as (the type of parent material, topography, drainage condition, climate conditions). Classification of soil can be implemented based on laboratory index property results and referring international classification standards.

In order to achieve characterization, necessary data have been collected from local investigation and consulting firms. Before selecting primary sample locations, visual site investigation accomplished and necessary information gathered regarding to soil formation and distribution throughout the sub city.

Accordingly, index and engineering properties were determined from laboratory tests, and further analysis and interpretations have been made by integrating all laboratory tests with in-situ testing data. Geotechnical data base formulated based on the collected data.

Following the fieldwork laboratory testing and generating a geotechnical data base, all geotechnical and related data collected was integrated into a relational GIS-based database implemented in ArcGIS. This software made it possible to perform the data entry and its handling within a geo database formed by feature dataset, feature class and tables.

This chapter mainly focuses on methodologies adopted to achieve the main objectives of the research.

4.2. Data presentation

All important data gathered either from consulting firms or directly collected samples are presented in this portion.

4.2.1. Site reconnaissance

Reconnaissance survey of study area and visual investigation carried out by bare foot (along AKaki-River, nearby express way toll) and by vehicle (from Kality driving license station to Gelan III condominium, from Yerer-Goro round about to express way entrance and from Haile garment to express way) prior to sample collection. The relevance of this survey is attaining general outlook about the soil distribution, observing drainage conditions in to and out of the study area, assessing any construction problems related with the objective of the study.

4.2.2. Secondary data collection

Hence, the study area is very large and inaccessibility of rural locations taking only primary sample laboratory test results couldn't well represent the investigation area. Thus, secondary data should be collected from different soil investigation consulting firms.

The data gathered incorporates test pits and rotary drilling bore-hole logs, index and engineering properties test results with identified global coordinates. Seventy-two secondary test pits and boreholes characterizations and engineering properties data collected. The sources, type of data gathered and specific location of boreholes will be summarized as follows.

i) Specific location - KuyeFeche condominium
   Data source- Building design S.co., Number of borehole log data selected- twenty two/22, Index properties laboratory test results for selected bore holes-Natural moisture content, specific gravity,Atterberg limit and free swell, Engineering properties laboratory test results- Triaxial, Unconfiend compressive strength, one dimensional consolidation test and standard penetration test.
ii) Specific location- Akaki and Kality / distributed at various locations of the study area
   Data source- AddissGeosystems Plc., Number of borehole logs - nine/9, number of test pit- eleven/11, Index properties laboratory test results for selected bore holes and test

pits-Natural moisture content, sieve analysis, specific gravity, Atterberg limit and free swell, Engineering properties laboratory test results- Triaxial, Unconfiend compressive strength, and one dimensional consolidation tests.

iii) Specific location- Gelan I and Gelan II Condominiums

Data source- Saba Engineering, Number of borehole logs - seven/7, Index properties laboratory test results for selected bore holes and test pits-Natural moisture content, sieve analysis, specific gravity,Atterberg limit and free swell.

iv) Specific location- Tulu dimtu industry park

Data source- Gondwanna Engineering, Number of borehole logs- seven/7, Index properties laboratory test results for selected boreholes and test pits natural moisture content, sieve analysis, specific gravity, Atterberg limit and free swell. Engineering properties laboratory test results -Triaxial, Unconfiend compressive strength, and one dimensional consolidation tests.

v) Specific location- Kuyefeche condominium

Gondwanna Engineering, Number of borehole logs eight/8, Index properties laboratory test results for selected boreholes and test pits-Natural moisture content, sieve analysis, specific gravity, Atterberg limit and free swell. Engineering properties laboratory test results -Triaxial, Unconfiend compressive strength, and one dimensional conslidation tests.

vi) Specific location- Akaki and Kality / distributed at varios locations of the study area

Data source-Jeroccia Engineering, Number of boreholes - five/5, Index properties laboratory test results for selected boreholes and test pits natural moisture content, unit weight, Atterberg limit and free swell.

4.2.3. Primary samples

Field visual soil description was made and sample for laboratory testing were collected. Nine sampling areas were selected from different locations of the sub city and different ongoing construction sites disturbed samples were collected (at depth of one and half meter and three meters). Prior to undisturbed sample collection, classification of soils accomplished. For engineering properties investigation undisturbed samples collected at a depth of four meters by selecting three representative locations (take in consider of the soil classification) but in some areas boulders were encountered making the digging difficult.

Primary sample data and tests accomplished have been summarized as follows.

Data type- Primary, Number of samples taken- twenty-one/21 from nine excavation pits, Laboratory tests accomplished- EJ Engineering, Index property laboratory Tests natural moisture content, sieve analysis, specific gravity, Atterberg limit and free swell, Engineering property laboratory tests- One dimensional consolidation test, standard Proctor, permeability /constant head meter, unconfined compressive strength tests.

4.2.4. Exposures/outcrops

Out crops allow direct observation and sampling of various soil strata in situ for preliminary geological and geotechnical analysis. To fill the gap for inaccessible locations such as along Akaki River, north east farm land cultivation areas and behind Kuyefeche condominium project eleven surface exposure data collected using photograph and location assigned by hand GPS.

BH-ID	**Easting**	**Northing**	**Elevation**	**Data Type**	**Data Source**
BH -1	474090	987169	2183	Secondary	Addiss Geo System
BH -2	474109	987166	2183	Secondary	Addiss Geo System
BH -3	475650	983228	2173	Secondary	Addiss Geo System
BH -4	475652	983234	2173	Secondary	Addiss Geo System
BH-5	475638	983249	2173	Secondary	Addiss Geo System
TP-1	474670	985781	2154	Secondary	Addiss Geo System
TP-2	474682	985784	2155	Secondary	Addiss Geo System
TP-3	474693	985769	2154	Secondary	Addiss Geo System
TP-4	474702	985757	2154	Secondary	Addiss Geo System
TP-5	474715	985762	2155	Secondary	Addiss Geo System
TP-6	473091	983783	2135	Secondary	Addiss Geo System
TP-7	473107	983789	2135	Secondary	Addiss Geo System
TP-8	473104	983760	2135	Secondary	Addiss Geo System
TP-9	473117	983782	2135	Secondary	Addiss Geo System
TP-10	473137	983776	2135	Secondary	Addiss Geo System

TP-11	473139	983803	2135	Secondary	Addiss Geo System
BH-26	479449	986489	2151	Secondary	S-AddissLiwot
BH-27	477356	982976	2160	Secondary	S-AddissLominat
BH-28	473483	985942	2171	Secondary	S-AddissTana
BH-29	986243	474312	2162	Secondary	S-AddissShimeles
BH-1	479857	984314	2178	Secondary	Building Design Sco.
BH-25	480046	984970	2186	Secondary	Building Design Sco.
BH-34	480027	984798	2196	Secondary	Building Design Sco.
BH-36	480124	984765	2196	Secondary	Building Design Sco.
BH-45	480035	984652	2190	Secondary	Building Design Sco.
BH-81	480132	984891	2201	Secondary	Building Design Sco.
BH-103	480046	984970	2200	Secondary	Building Design Sco.
BH-119	480118	985061	2205	Secondary	Building Design Sco.
BH-126	480287	984999	2205	Secondary	Building Design Sco.
BH-250	480987	984972	2202	Secondary	Building Design Sco.
BH-325	481121	984975	2204	Secondary	Building Design Sco.
BH-403	481097	984797	2196	Secondary	Building Design Sco.
BH-500	480284	985377	2209	Secondary	Building Design Sco.
BH-582	480760	985313	2213	Secondary	Building Design Sco.
BH-679	480360	985953	2201	Secondary	Building Design Sco.
BH-705	480536	985481	2209	Secondary	Building Design Sco.
BH-789	480999	985481	2216	Secondary	Building Design Sco.
BH-946	481465	984353	2205	Secondary	Building Design Sco.
BH-952	481519	984415	2209	Secondary	Building Design Sco.
BH-975	481453	984142	2210	Secondary	Building Design Sco.
BH-1540	483175	98175	2208	Secondary	Building Design Sco.
BH-1608	483450	981825	2218	Secondary	Building Design Sco.
BH-6	474360	982127	2185	Secondary	S-Gelan-I
BH-7	474551	981883	2107	Secondary	S-Gelan-I
BH-8	474372	981834	2152	Secondary	S-Gelan-I

BH-9	474528	981480	2098	Secondary	S-Gelan-II
BH-10	474814	981518	2101	Secondary	S-Gelan-II
BH-11	474851	981432	2106	Secondary	S-Gelan-II
BH-12	474962	981367	2099	Secondary	S-Gelan-II
TP -13	474876	983078	2160	Primary	Lab EJ Engineering
TP -14	474757	984501	2164	Primary	Lab EJ Engineering
TP -15	474284	982768	2157	Primary	Lab EJ Engineering
TP -16	479423	980694	2158	Primary	Lab EJ Engineering
TP -17	475042	985915	2153	Primary	Lab EJ Engineering
TP -18	479716	982090	2149	Primary	Lab EJ Engineering
TP -19	474250	981394	2083	Primary	Lab EJ Engineering
TP -20	478858	985521	2182	Primary	Lab EJ Engineering
TP -21	480433	979941	2151	Primary	Lab EJ Engineering
TP -22	480956	979168	2139	Secondary	Lab EJ Engineering
TP -23	480281	987340	2167	Secondary	Lab EJ Engineering
TP -24	479706	987324	2165	Secondary	Lab EJ Engineering
Tp-25	474006	986180	2184	Secondary	Lab EJ Engineering
Tp-26	474437	984327	2169	Secondary	Building Design Sco.
BH-1337	481296	982553	2214	Secondary	Building Design Sco.
BH-1339	482229	982596	2214	Secondary	Building Design Sco.
BH-1343	482290	982699	2213	Secondary	Building Design Sco.
BH-1365	482326	982291	2204	Secondary	Building Design Sco.
BH-1373	482143	982324	2197	Secondary	Building Design Sco.
BH-1399	482430	982406	2209	Secondary	Building Design Sco.
BH-1412	482543	982598	2226	Secondary	Building Design Sco.
BH-1548	483290	981925	2223	Secondary	Building Design Sco.
BH-1'	480699	986400	2200	Secondary	Exposure Behind KoyeFeche
BH-2'	481508	985192	2199	Secondary	Exposure Behind KoyeFeche
BH-3'	482481	983884	2265	Secondary	Exposure Behind KoyeFeche
BH-4'	481795	983782	2208	Secondary	Exposure Behind KoyeFeche

BH-5'	481540	983588	2193	Secondary	Exposure Behind KoyeFeche
BH-7'	479258	987880	2205	Secondary	Exposure Along Akaki River
BH-8'	478938	988006	2199	Secondary	Exposure Along Akaki River
BH-9'	478400	988087	2202	Secondary	Exposure Along Akaki River
BH-10'	477787	988039	2152	Secondary	Exposure Along Akaki River
BH-11'	476962	987478	2179	Secondary	Exposure Along Akaki River
BH-12'	476879	986176	2142	Secondary	Exposure Along Akaki River
BHIPKL-1	477937	985727.8	2184	Secondary	Gondwana Engineering
BHIPKL-10	478537	985127.8	2183.8	Secondary	Gondwana Engineering
BHIPKL-12	478337	984727.8	2177.4	Secondary	Gondwana Engineering
BHIPKL-17	477937	984527.8	2169.7	Secondary	Gondwana Engineering
BHIPKL-29	479137	984527.8	2170.2	Secondary	Gondwana Engineering
BHIPKL-40	479178	984270.3	2166.5	Secondary	Gondwana Engineering
BHIPKL-73	478783	984164.3	2162.1	Secondary	Gondwana Engineering
BH-13	475942	985942	-	Secondary	Jeroccia Engineering
BH-14	479438	986489	-	Secondary	Jeroccia Engineering
BH-15	477356	982976	-	Secondary	Jeroccia Engineering
BH-16	481243	981251	-	Secondary	Jeroccia Engineering
BH-17	479843	980708	-	Secondary	Jeroccia Engineering

Table 4.1. Global coordinates of bore hole and test pit locations

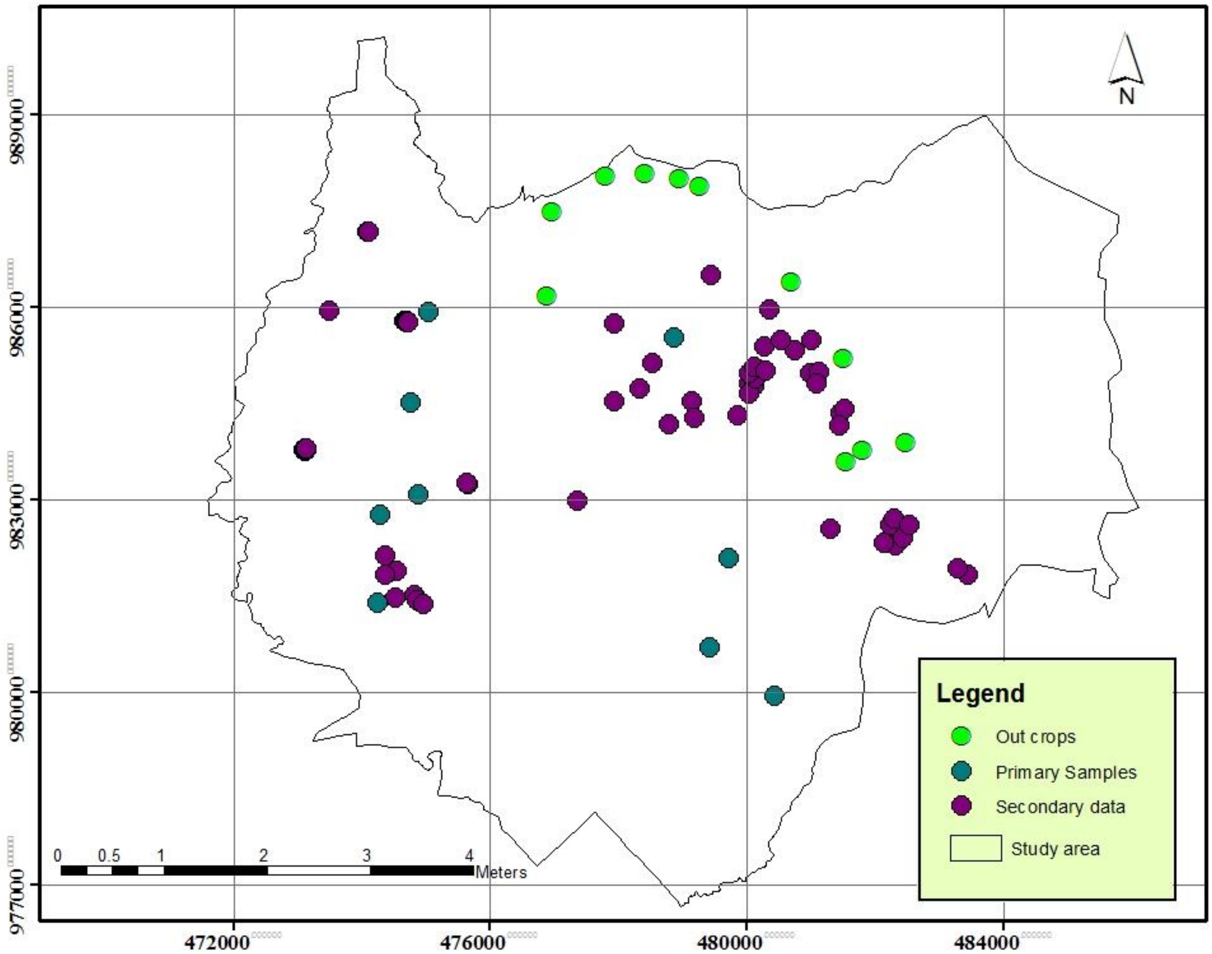

Fig 4.1. Distribution of bore holes and test pits within the study area

CHAPTER FIVE

Result Discussion and soil mapping

5.1. Result Discussion

5.1.1. General

Soil is erratic. Based on the laboratory test results, soil characterization of the is difficult. The result of moisture content, specific gravity liquid limit, plasticity limit and free swell show that there is wide variable value of range not only on spatial bases but on depth bases too. Even with in the same layer of soil profile or similarly classified soil types has very variable test results of moisture content, specific gravity and free swell.

The topography of the research area is mainly flat to gentle slope. Steep slopes are limited along main river stream banks. Accordingly, the soil in the study area is predominantly residual soil. Moreover, the upper most layer of most of the research area is covered by black cotton soil (lacustrine soil) with dark to grey color and high plasticity and expansive nature which is the case for poorly drained conditions.

Engineering data especially used by geotechnical engineers are costly, and difficult to obtain and analyses. It is difficult to determine the soil types and change of layers at every point on the site. Engineers depend on information from representative samples to estimate the soil properties. In this thesis, a method of analyzing and geotechnical soil mapping using GIS environment accomplished.

5.2 Laboratory Tests

5.2.1. Index properties

Moisture content, specific gravity liquid limit, plasticity limit and free swell laboratory test results show that there is wide variable value of range both on spatial and depth bases. These makes soil characterization of the study area very hard. Even with in the same layer of soil profile more soil types are found.

Test results show that three soil types are dominantly exist in the study area. MH, CH and SM are dominant soil types. CL, GM, SC, CL – ML, & SC – SM exist rarely in the study area.

Various laboratory tests were conducted to discuss the results on index properties of soils. Disturbed samples at depth of 1.5, 3 and 4.5 meters below natural ground surface (NGS) were collected to conduct the accompanying laboratory tests.

5.2.1.1. Natural moisture content

The numbers of primary samples taken were 17 out of which three undisturbed and fourteen disturbed from seven excavation pits. AASHTO T-265 test procedure has been subsequently implemented.

The numbers of secondary data samples taken were 178 at various specified depth below natural ground level from 78 boreholes and test pits, ASTM D-2216-98 test procedure has been subsequently implemented.

For undisturbed samples (the primary ones) samples brought to the laboratory and measuring the weight of moisture can and weight of the can with moist soil put it in to drying oven at a temperature of 105+5°c for 24 hours. Then after, the natural moisture content was determined.

Necessary cares were taken during undisturbed sample collection stages, the top and bottom of the Shelby sample taking tube were immediately wax sealed and covered with polyethylene bags that are labeled with necessary information for natural moisture content and other subsequent laboratory tests.

For disturbed samples, this test was done by taking moisture can and balance to the field. In the site the weight of the moisture can and the weight of can with moist soil was measured. Then the sample was brought to the laboratory and put it in to drying oven at a temperature of 105+5°c for 24 hours. Then after, the natural moisture content was determined.

The natural moisture content margin in the study are becomes 12.0% to 68.5%.

5.2.1.2. Specific gravity

Over all primary samples taken for this test were 17 from seven sample locations. The tests were conducted according to AASHTO 084-94 test procedures. According to the test procedures there are two methods for performing specific gravity. These are Method-A, procedures for oven dried specimen and Method-B, procedure for moist specimen. For specimens of organic soils and highly plastic, fine-grained soils procedure B shall be the preferred method. In this thesis work Method-B is the preferred method referring the sample type.

Secondary samples tested were 139 from forty-eight boreholes and test pits. The tests were conducted according to ASTM D854 test procedures. The specific gravity of Akaki-Kality sub city ranges from 2.29 to 2.89.

5.2.1.3. Grain size distribution

Over all primary samples taken for this test were 17 from seven sample locations. The tests were conducted according to AASHTO T-265 test procedure. Only dry sieve analysis test conducted.

Secondary samples tested were 139 from forty-eight boreholes and test pits.

The percentage of fine and coarse of the study area ranges from 0.0 to 99.9 % and 0.1 -95.9 % respectively.

5.2.1.4. Atterberg Limits

Twenty-one primary samples taken were from nine excavation pits. One hundred seventy-six /176 secondary samples were tested from 38 boreholes and test pits at various specified depth below natural ground level.

The tests were conducted according to AASHTO T-88 and T-90 test procedures for primary samples and according to ASTM D4318 test procedures for secondary sample.

The liquid limit and plasticity index of Akaki-Kality sub city ranges from 25-113% and 4-74% respectively.

5.2.1.5. Free swell

Twenty-one primary samples were taken from nine excavation pits. One hundred six /106 secondary samples were tested from 22 boreholes and test pits at various specified depth below natural ground level.

The tests were conducted according to AASHTO test procedures for primary samples and according to ASTM D4318 test procedures for secondary sample tests.

From the test result we obtain the free swell of the soil under investigation ranges from 20% to 280%.

5.2.2. Engineering properties

In order to visualize engineering characteristics of soil in the study area basic laboratory tests conducted using both disturbed and undisturbed samples at three selected locations.

5.2.2.1. Compaction

Three primary samples were taken at Tulu dimtu, Gelen III, Near Church Kukuam locations. The tests were conducted according to AASHTOT-180 test procedure.

Two types of compaction tests routinely performed are: (1) The Standard Proctor Test, and (2) The Modified Proctor Test. In this thesis the Standard Proctor Test is used.

From the test results the maximum dry density (MDD) ranges from 1.63-1.69g/cm3 and the optimum moisture content ranges 20.00 to 29.80 percent.

5.2.2.2. Consolidation

Three primary samples were taken from three undisturbed samples taken at Tulu dimtu, Gelen III, Near Church Kuskuam locations. All three samples were taken at depth of 4.00m below natural ground level.

Nine secondary sample test results selected from secondary data sources and the samples were taken at various depths below natural ground water level.

The one dimensional consolidation tests were conducted according to AASHTOT-216 test procedures for primary samples and according to ASTM- D2435-04 test procedures for secondary sample.

From the test results the initial void ratio (e_o) of soil in the study ranges from 0.237-1.81 and the compression index (Cc) ranges 0.215 to 1.047.

5.2.2.3. Unconfined compressive strength

Three primary samples were taken from three undisturbed samples taken at Tulu Dimtu, Gelen III, Near Church Kuskuam locations. All three samples were taken at depth of 4.00m below natural ground level.

Thirty-eight secondary sample test results selected from secondary data sources and the samples were taken at various depths below natural ground water level.

The UCS tests were conducted according to AASHTOT-208test procedure for primary samples and according to ASTM-D2166odometer test procedures for secondary sample.

From the test results the unconfined compressive strength of Akaki-kality soil ranges 10.21-376KPa.

5.2.2.4. Permeability test /Constant head meter

Three primary samples were taken from three undisturbed samples taken at Tulu dimtu, Gelen III, Near Church Kuskuam locations. All three samples were taken at depth of 4.00m below natural ground level.

These tests were conducted according to AASHTOT-215 test procedures.

From the test results the permeability of Akaki-kality soil ranges $3.58x10^{-4}$ to $5.51x10^{-4}$ (K_{20} cm/sec).

5.2.2.5. Triaxial test

Twenty-six secondary test results selected from secondary data sources samples and were taken at various depths below natural ground level.

These tests were conducted according to ASTM D 3080 test procedures.

From the test results the cohesion of Akaki-kality soil ranges7-148 $KN/m^2$and angle of internal friction ranges 2^0-40^0

All primary and secondary test results summarized in appendix A-1.

5.3. Soil Classification

The most widely used soil classification systems for engineering purposes are American Association of State Highway and Transportation Officials (AASHTO) and Unified Soil Classification System (USCS). The AASHTO system of soil classification comprises seven groups of inorganic soils from A-l to A-7 with 12 subgroups in all. The system is based on particle-size distribution, liquid limit and plasticity index. On the other hand, the Unified Soil Classification System (USCS) is based on the recognition of the type and predominance of the constituents considering grain-size, gradation, plasticity and compressibility. It divides soil into three major divisions: coarse-grained soils, fine grained soils and highly organic soils.

The AASHTO classification system is quite popular in road works (Lucian, 2006). For the present study Unified Soil Classification (USCS) will be adopted which is a general type of classification system; and both the light and dark grey soils of the study area soils fall above the A- line and below A-line which is under low plastic silt (ML) high plastic silt (MH) and high plastic clay (CH) and low plastic Clay (CL) soil types.

Highly plastic silt (MH), Sandy silt (SC) and highly plastic clay (CH) are the dominant soil types.

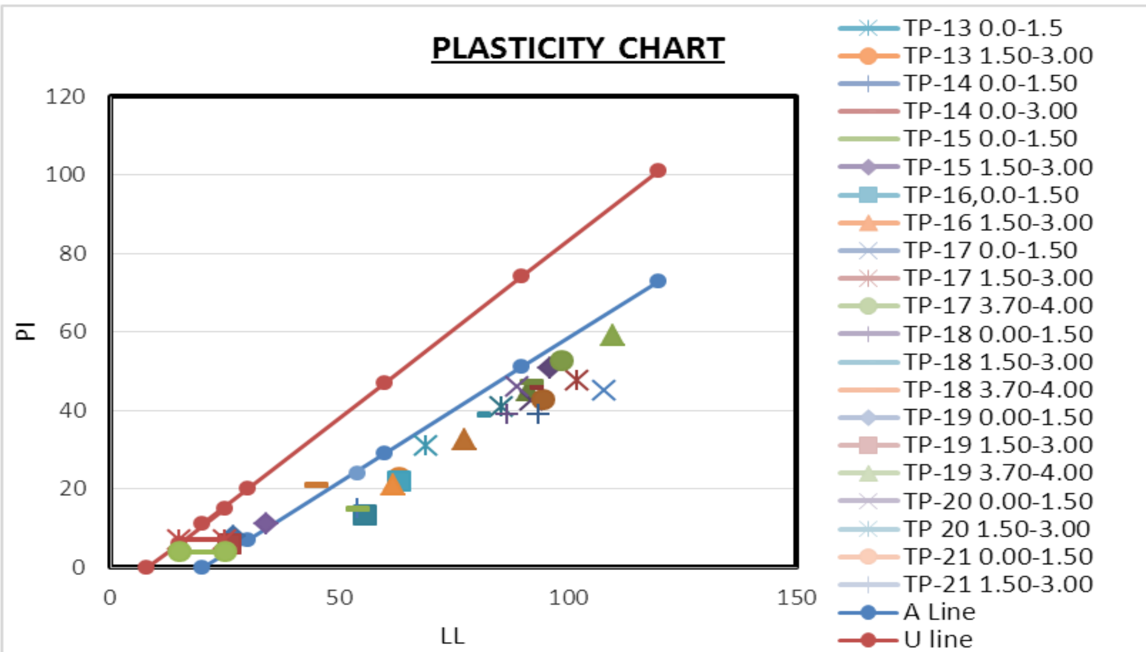

Fig 5.1. Plasticity chart of the soils in the study area

Primary and secondary soil classification summarized in Appendix A-1.

5.4. Soil Mapping Units

General

Geotechnical information acquired from site and laboratory tests are vital for a safe and economical design of building and infrastructure works especially in land development projects. Such data can be presented in form of geotechnical soil maps using GIS for to engineers, planners and land development professionals. In this chapter, the results of this study stored in GIS systems are processed and presented into an engineering soil map describing the soil types. Then, the data are always available and this can reduce a lot of time to retrieve them. The soil mapping is used the entire assessment of the soils geotechnical properties that were collected through visual site reconnaissance, the development of a geotechnical database from previous borehole logs / laboratory test results, primary pit laboratory test results and analyzing soil formation parameters basically topography and drainage.

Accordingly, in developing the soil map the subsequent steps are followed: rating the soil classification results; compilations of the results of this research; and delegating soil contacts using all the physical understanding of the area related to slope, drainage, lithology and geology.

In this soil map, the deeper soil parameters were considered in spots where the upper most layers are less than 1.0 meter below natural ground. This is because of the assumption that the upper layer will be excavated in normal engineering practice and the entire engineering practices will be determined by the underneath layer.

It is defined that the major (around 80%) lithology (geological unit) of the study area comprises Akaki basalt scoria and scattered cones with associated volcanic lava (Fig 3.2). The topographic distribution also shows that around 75% of the area is a flat terrain (Fig 3.4). Accordingly, a minor soil type variation is observed pertaining geology and topography.

In the other hand, most of the soil variations are affected by the distribution of the river and streams. Thus, soil mapping units' contact are most followed the drainage pattern and distribution (Fig 3.5).

In the soil map, the northern eastern part of the study area is not mapped as the area is covered by the rock formations. The rest is mapped in to five soil mapping units; namely, MH (Highly plastic Silt), CH (Highly plastic clay) SM (Sandy silt), GM (gravelly silt), and SC (sandy clay). MH and CH are the predominant soil types while the others are in minor proportion.

5.4.1. MH (Highly plastic Silt)

It is the most dominant soil in the study area which is observed in 21boreholes and 4 test pits at variable depths.

From index test results the soil has liquid limit and plasticity index 47% (BHIPKL-17) to 110% (BH-7) and 13% (BH-45) to 62% (BHIPKL-10) respectively. This implies the soil behaves from low degree of expansive to very high degree of expansive. Borehole BHIPKL-10 which is secondary data, with 62% PI and 72% clay fraction should be classified as CH besides it is classified as MH. Moisture content ranges from 14.07% (TP-18 primary sample collected during dry season/May) to 64% (BHIPKL-1 secondary sample at Kilinto Industry Park, the sample collected relatively during wet season/ at the end of September). Specific gravity ranges from 2.45 to 2.83. Free swell range from 60 to 260% showing the soil varies from marginal expansive range to highly expansive range.

From engineering tests the soil has UCS ranges from 25.94KN/M^2 (TP-18, soft consistency range) to 220KN/M^2 (very stiff consistency). Compressibility Index and Initial void ratio ranges from 0.12 (TP-18, low compressibility) to 0.379 (BH-1, medium range compressibility) and 0.907 (BH-1) to 1.52 (TP-19) respectively, the hydraulic conductivity (K) implies 5.5x10^{-4} cm/sec which implies impervious soil type, cohesion (C) ranges from 17 to 148KPa and angle of internal friction (Ø) ranges from 2 to 23 degree. The summary of laboratory test result of this soil is attached in appendix A-2.

MH soil is a sediment material with semi pervious to pervious permeability, highly compressible, fair to poor shear strength and poor workability characteristics exhibited on flat, poorly drained water logging study area locations. It covers 51.24 square kilometer area which is around 43.4% of the study area.

5.4.2. CH (Highly plastic Clay)

It is the second most dominant soil in the study area. It is seen in 17 boreholes and 3 test pits and at variable depths.

From index tests the soil has liquid limit and plasticity index 50.75% (Tp-13) to 113% (BHIPKL-10) and 23% (BH-34, medium expansive range) to 74% (BHIPKL-10, highly expansive range) respectively. Moisture content test ranges from 12.54 (TP-13) to 57% (BHIPKL-1 sample collected during wet season/September). Specific gravity ranges 2.58 to 2.79, free swell range 120% (BH-34) to 220% (BH-676) showing the soil is an expansive soil.

From engineering tests the soil has UCS ranges from 21.6KN/M2 (vey soft consistency range) to 124KN/M2 (Stiff consistency range). Indicating the soil varies from soft to very stiff consistency. The optimum moisture content and maximum dry density (MDD) exhibited 28.5% and 1.59 g/cm^3 respectively. The summary of laboratory test result of this soil is attached in appendix A-3.

CH soil is residual soil with impervious, poor shear strength, poor workability and very expansive characteristics exhibited on flat poor drainage terrain condition of the study area. It covers 26.14 square kilometer area which is around 22.1% of the study area.

5.4.2. SM (Sandy Silt)

It is the third most dominant soil in the study area. It is seen in 13 boreholes and 3 test pits and at variable depths.

From index tests the soil has liquid limit and plasticity index 25% (BH-1339) to 69.6% (TP-14) and 4% (BH-1337, non-expansive) to 28.18% (TP-15, non-expansive) respectively. Moisture content tests ranges from 12% (BH-1339, sample collected during dry season/March) to 42.23% (BH-34). Specific gravity ranges 2.55 to 2.891, free swell range 30 (BH-45, non-expansive) to 124% (TP-14, expansive).

From engineering tests the soil has UCS ranges from 49.52KN/M2 (BH-34, soft consistency range) to 290.23KN/m2 (BH-1373, very stiff consistency range). The summary of laboratory test result of SM soil is attached in appendix A-4.

SM soil is semi pervious to impervious permeability condition, good shear strength, fair workability and low compressibility characteristics exhibited around river banks with steep slope and well drained terrain condition of the study area. It covers 16.13 square kilometer area which is around 13.22% of the study area.

North and north east boundaries with very steep slope expected dominantly fragmented rock covers 17.29 square kilometer area which is 13.22% of the study area.

5.4.4.Other soil types

Rarely encountered soil types are SC (Sandy clay) in 5 bore hole and test pits, ML (low plastic silt) in 2 test pits and 1 borehole, GM (Gravely silt) in 2 boreholes and 1 test pits, SM-SC (Sandy silt/ Sandy clay) in 1 bore hole.

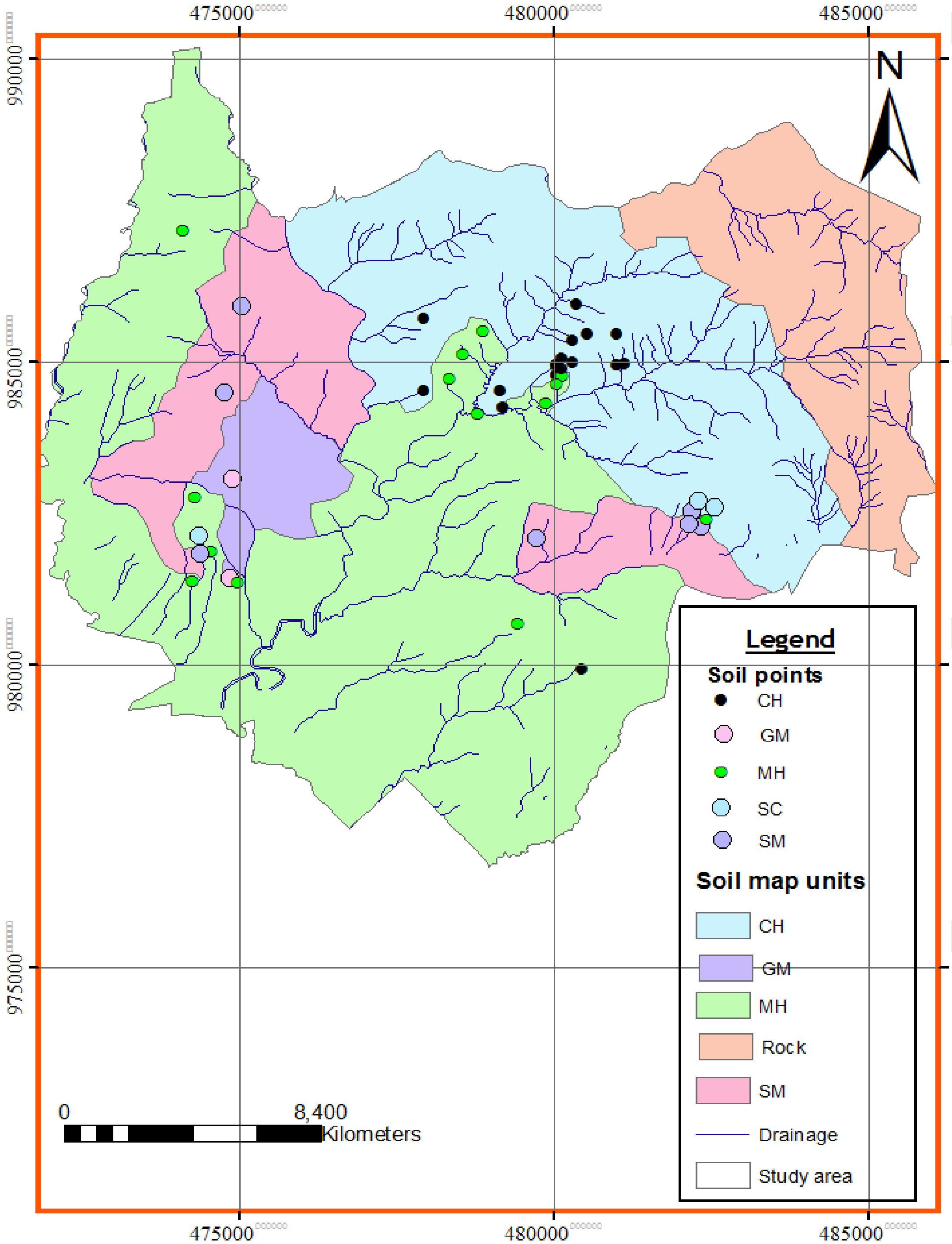

Fig 5.2. Geotechnical soil map

5.5. Cross section profiles

General

Geological cross sections are graphical representations of vertical slices through the earth used to clarify or interpret geological or. There are two major classes of cross sections.

- ✓ Structural cross sections: -which show the present day geometry of an area.
- ✓ Stratigraphic cross sections: - which show prior geometric relationships by adjusting the elevation of geological units to some chosen geological horizon.

In this thesis five strati-graphic cross sections have been selected along bore holes and test pits and soil profiles generated to over view soil distribution accordingly. Drainage and topographic conditions of the study area were essential parameters in the selection of cross section profiles.

Soil cross sections have been taken by connecting bore holes and test pits across the research area. Total of five cross sections have been taken. These sections are selected in a way that could help see the variation of soil layers and thickness against topography and drainage.

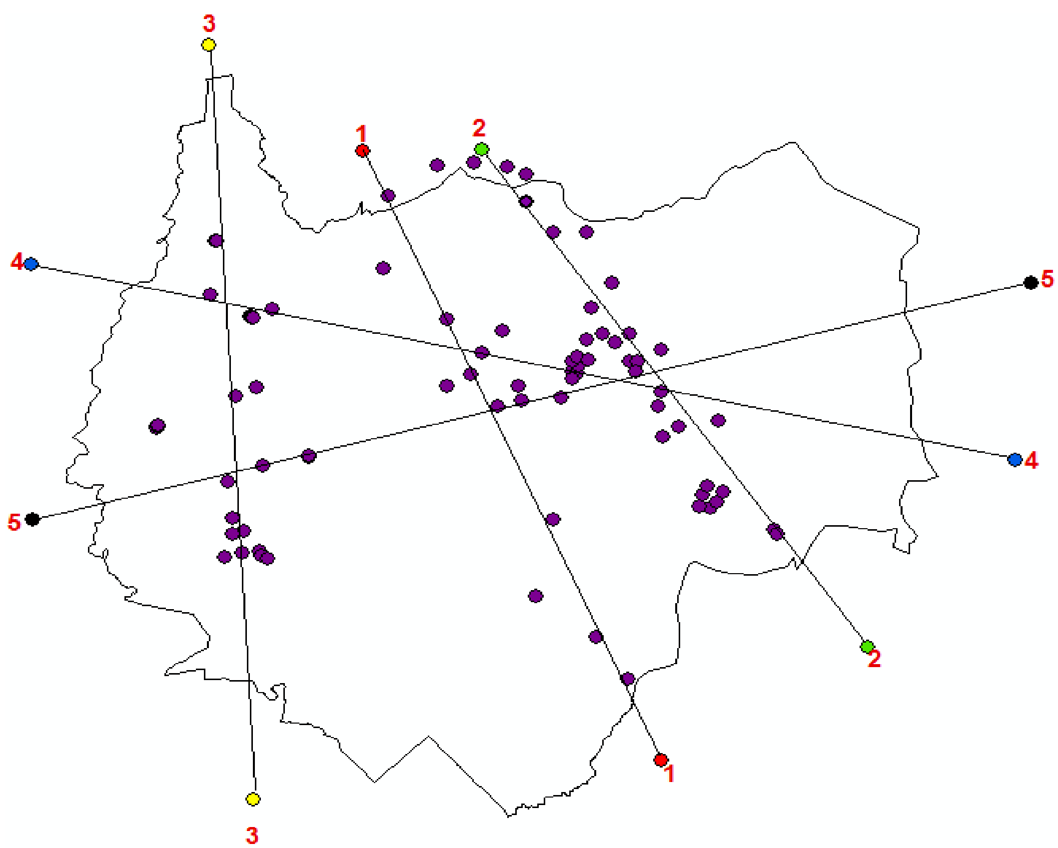

Fig 5.3. Cross-section profile layout

Section 1-1 Along BH-11'-HIPKL-1, BHIPKL-12, BHIPKL-73, TP-18 and TP-21

The first layer along this section is black cotton soil with a thickness of 1.5m around TP-21 and TP-18. The second layer witnessed Silty clay/clayey silt soil maximum of 10m around BHIPKL-1 and Red Ash with a thickness of 2m around TP-18/TP-21. The third layer is decomposed basalt with a thickness of 4m around BH-11' and BHIPKL-1.

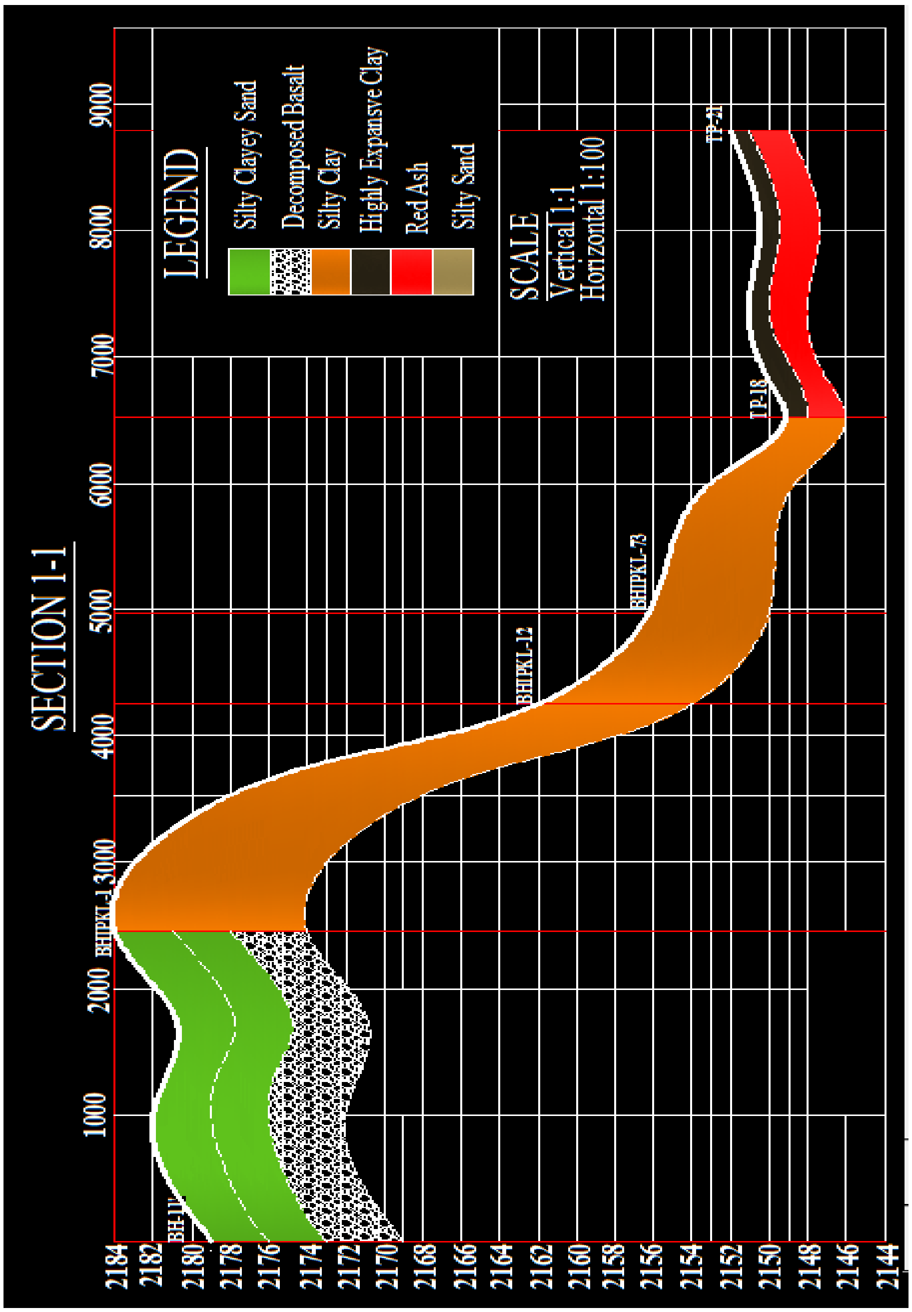

Fig 5.4. Geotechnical cross-section 1-1

Section 2-2 Along BH-7’, TP-24, BH-789, BH-952, BH-1584

The first layer along this section is black cotton soil with a minimum thickness of 1.5m around TP-24/BH-789 and a maximum thickness of 3.0m around BH-952. Silty clayey sand layer is also first layer with a thickness of 3.5m around BH-1584. The second layer witnessed Silty clay/clayey silt soil maximum thickness of 10m around BH-952 and 7.0m around BH-1584. The third layer is decomposed basalt with a thickness of 10m around TP-24 and BH-789.

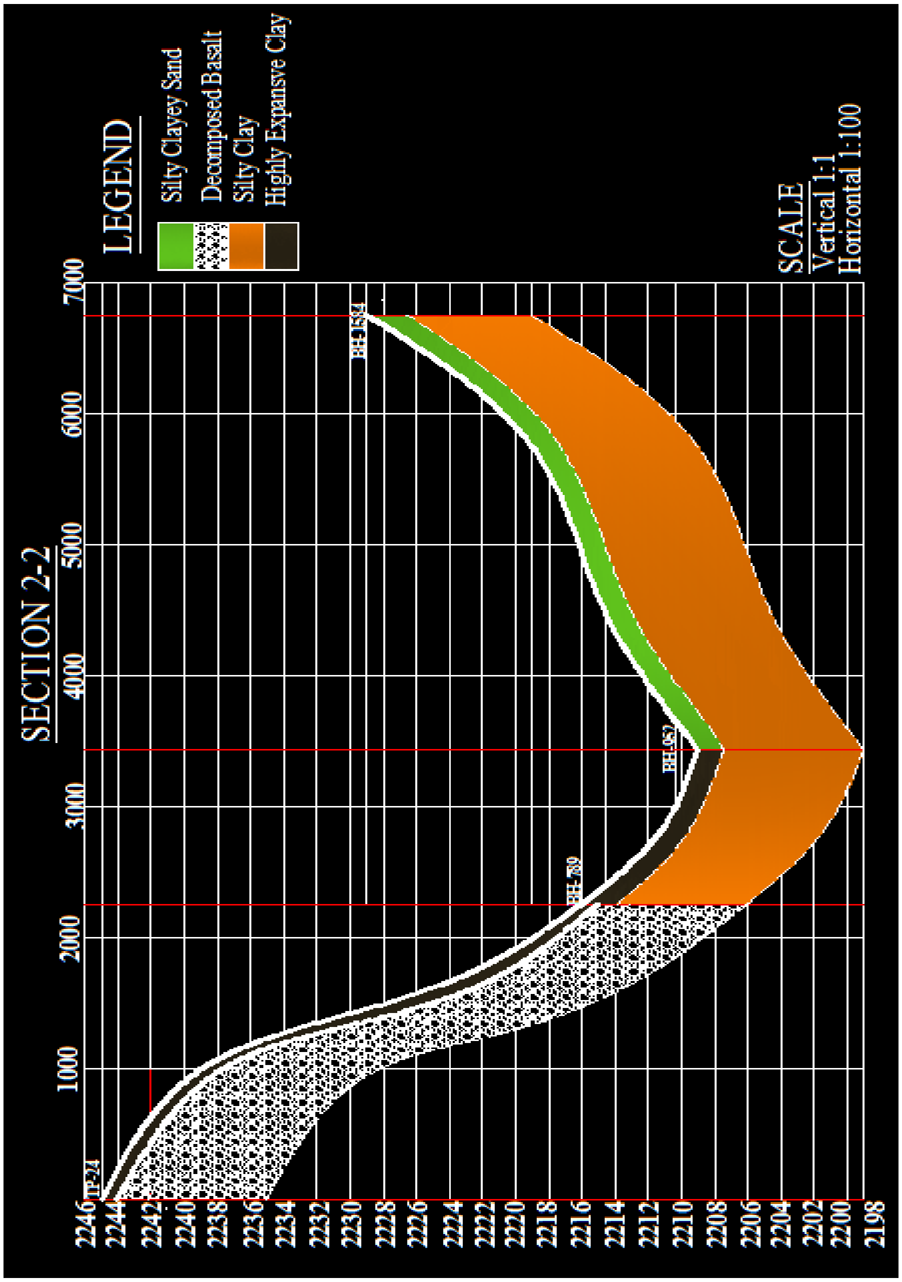

Fig 5.5. Geotechnical cross-section 2-2

Section 3-3 Along BH-1, TP-26, BH-6, BH-9

The first layer along this section is black cotton soil with a minimum thickness of 3.0m around BH-1/TP-26 and Silty clay layer with a thickness of 1.0m around TP-26/BH-6. Silty clay is second layer with thickness of 7.0m around TP-26/BH-1 and Silty sand strata with a thickness of 2.0m around TP-26/BH-6. Silty sandy gravel 7.0m thick around TP-26/BH-6 is third layer. Section from BH-6 to BH-9 is a single low plastic Silt layer with 10.0m thickness.

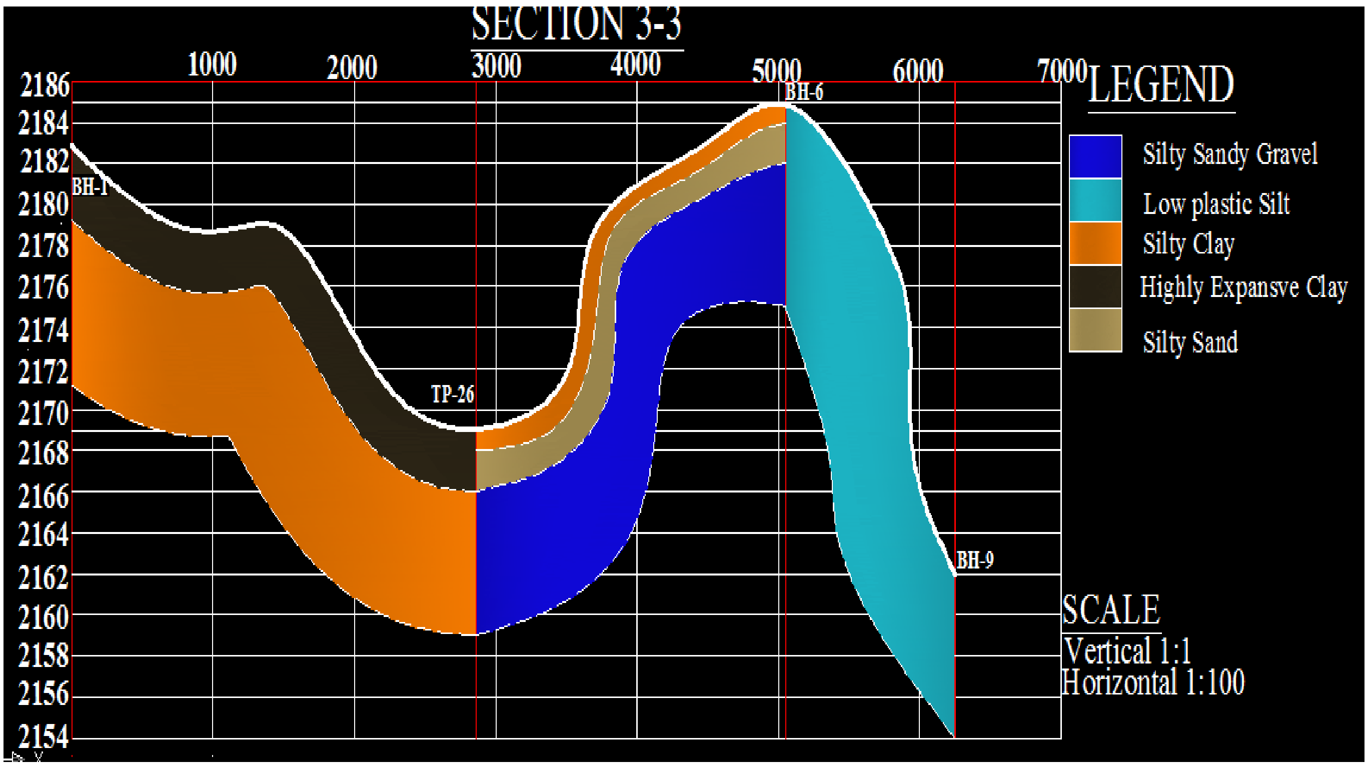

Fig 5.6. Geotechnical Cross Section 3-3

Section 4-4 Along TP-25, -TP-17, BHIPKL-10, BH-34 and BH-952

The first layer along this section is black cotton soil with a thickness of 3.0m around TP-25/TP-17. Section from TP-17 and BHIPKL-10 is a single layer of Silty clay with a thickness of 4.0m. Section from BHIPKL-10 to BH-952 is also a single Silty clay layer with a thickness of 10.0m.

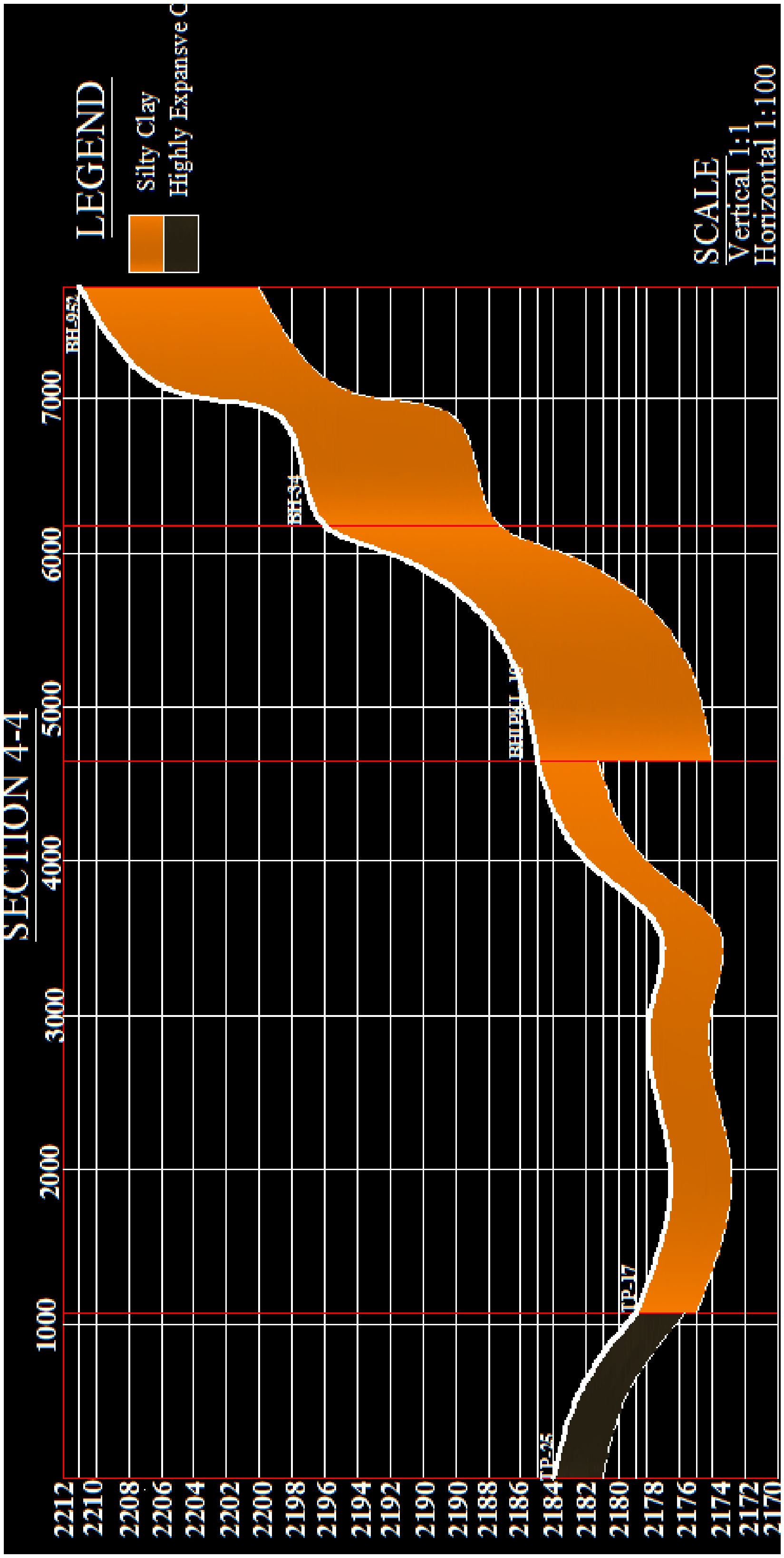

Fig 5.7. Geotechnical Cross Section 4-4

Section 5-5 Along TP-13, -BH-3, BHIPKL-73, BHIPKL-40 and BH-403

The first layer along this section is black cotton soil with a minimum thickness of 2.0m around TP-13/BH-3 and a maximum thickness of 4.0m around BHIPKL-73. Decomposed basalt is second layer 2.0m thick around TP-13/BH-3 and Sandy silt strata with 4.0m thick around BHIPKL-73. Section from BHIPKL-73 to BH-403 is a single Silty clay layer with a thickness of 6.0m.

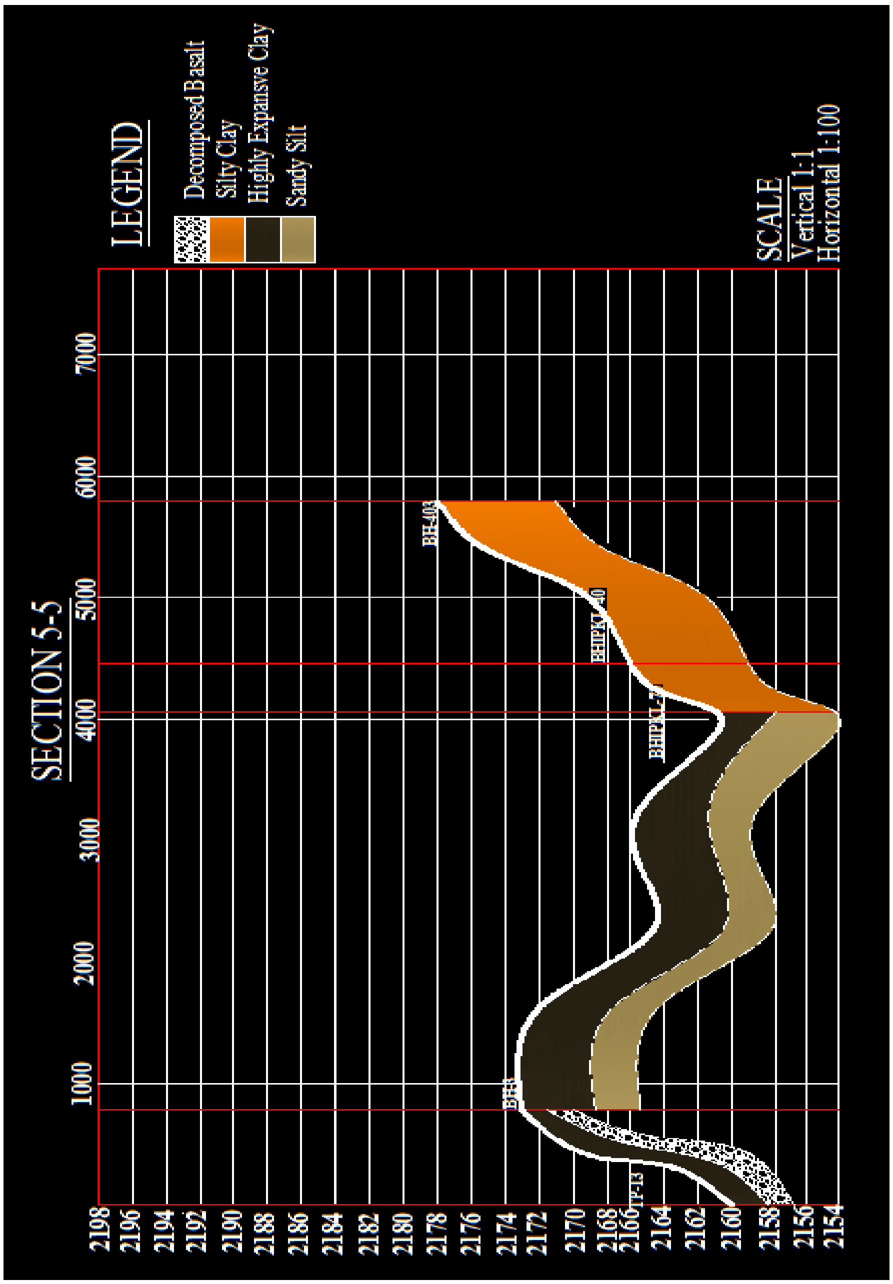

Fig 5.8. Geotechnical Cross Section 5-5

CHAPTER SIX

Conclusion and Recommendation

6.1 Conclusion

Soil investigation, characterization, distribution and engineering property compiled data, is too crucial to reveal the feasibility and safety of civil works. The general objectives of this thesis project comprehend to define the engineering properties, distribution and characterization of soil in Akaki-Kality sub city. The methods applied on this thesis incorporates reconnaissance survey, secondary data collection from different private and governmental investigation and consulting firms, index and engineering laboratory tests conducted using sample collected from ongoing construction pits, generating geotechnical soil maps using arc GIS software tools, compiling data and preparation of geotechnical data base and laboratory tests result analysis.

Issues related with soil formation and deposition, general types of soil and various index and laboratory tests and geotechnical soil mapping briefly reviewed accordingly. Previously accomplished researches affiliated with investigation on engineering properties also summarized.

Akaki Kality is one of the ten sub cities of Addis Ababa and incorporates the largest plot area and also one of the main expansion corridors of the city. Akaki basalt (bofa basalt), Central volcanic of Wochecha, Furi, yerer porphyritic trachytic lava and Ababa basalt are the three lithological constituents in the sub city. Elevated areas within the study area north and north east peripheries possess residual soils few centimeters in depth. Flat low land locations, of southern peripheries and along the main river basin (Akaki River) transported soil deposits are predominant. The highest mean annual temperature of Addis Ababa recorded in Akaki-Beseka meteorological station. Runoff from mountainous elevated locations of the city flows downstream, to the low land locations as Akaki-Kality.

The following conclusions are drawn based on the secondary and primary laboratory data of this research: -

- The natural moisture content of Akaki kality sub city ranges from 12.0% to 68.5%.
- The specific gravity ranges from 2.29 to 2.89.
- The percentage of fine and coarse fractions ranges from 5.0 to 99.9 % and 0.1 -95.9 % respectively.

- The liquid limit and plasticity index of Akaki-Kality sub city ranges from 25-113% and 4-74% respectively.
- The soil types in the study area have free swell ranges from 20% to 280%.
- According to the unified soil classification system the dominant soil types in the sub city are MH, SM, CH and ML, GM and SM-SC soil types rarely visualized.
- The maximum dry density (MDD) of soils in the study area ranges from 1.63-1.69 g/cm3 and the optimum moisture content ranges 20.00 to 29.80 percent.
- The initial void ratio (e_o) of soil in the study area ranges from 0.237-1.81 and the compression index (Cc) ranges 0.215 to 1.047.
- The unconfined compressive strength ranges 10.21-376 Kpa.
- The permeability of Akaki kality soil ranges $3.58x10^{-4}$ to $5.51x10^{-4}$ (K_{20} cm/sec).
- The cohesion of soil ranges 7-148 KN/m^2 and angle of internal friction ranges 2^0-40^0
- In the study area soil layers of black cotton, silty clay/clayey silt soil, Sandy silt/ silty sand sandy gravel encountered.
- The soil of the study area is very erratic both spatially depth wise.

6.2. Recommendation

- ✓ The top soil of the study area is predominantly highly expansive clay. Light structures with shallow foundations lay on highly expansive soils needs either stabilization mechanism or remove the expansive layer and replace with an appropriate material for the safety of the structure.
- ✓ The numbers of test pits taken are not enough and secondary data also not accessible for cultivation/rural portion of the sub city thus it is too difficult to generalize the engineering properties of soils found in Akaki-Kality sub city. However, by increasing the number of test pits, more detail results can be obtained.
- ✓ Further investigation should be accomplished on wet sieve analysis in order to classify the fine content to silt and clay proportions.
- ✓ It will be appreciable to conduct chemical tests on residual soils to attain detail information on chemical weathering process of soil formation.

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Appendix A

Appendix B

Appendix C

Appendix D

DECLARATION

I hereby declare that this thesis is my original work that has been carried out under the consultancy of Dr. Trufat Hailemariam, School of Architecture and Civil Engineering, Addis Ababa Science and Technology University during the year 2017 as part of the Degree of Master of Science in Geotechnical Engineering in accordance with the rule and regulation of the institute. I further declare that this work hasn't been submitted to any other University or Institution for the award of any degree or diploma and all sources of materials used for the thesis have been duly acknowledged.

Zemene Muche

Signature______________________________

School of Architecture and Civil Engineering, Addis Ababa Science and Technology University

February, 2019